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REPORT OF COMMITTEE ON PIPE LINE FRICTION COEFFICIENTS

And Effect of Age Thereon.

[*Received July 1, 1935.*]

LETTER OF TRANSMITTAL.

To the New England Water Works Association,

Gentlemen: On November 8, 1933, the Executive Committee of your Association authorized the formation of a committee to compile information on "Pipe Line Friction Coefficients."

Your Committee sent out numerous questionnaires to obtain data relative to coefficient values and the effect of age and water quality thereon. The accompanying report has been compiled from the information received in these questionnaires and from other available data.

The following general conclusions may be drawn from the data submitted to your Committee:

1. The average *actual* loss in capacity of tar-coated cast-iron pipe after 30 years of service, based on a total of 473 tests in 19 different systems, was 52 per cent.

The loss *predicted* in the Williams-Hazen Tables for mains of similar age and diameter (average 20.5 in.) and for "average soft unfiltered river water" is 32.3 per cent.

2. Based upon the data available to the Committee, the Williams-Hazen age-coefficient relation is applicable *primarily* to large-diameter mains carrying relatively inactive water.

3. For small-diameter mains carrying active water, the *actual* loss after 30 years may be twice the Williams-Hazen *predicted* loss.

4. Other factors being equal, the data show marked correlation between pH value of water carried and rate of capacity loss, average conditions reported indicating for supplies with a pH value of 6.5, twice the loss observed in supplies with a pH value of 8.0.

Scope of Report. The principal objective in preparing this report has been the presentation of heretofore unpublished data upon friction coefficients of tar-coated cast-iron pipe, with particular reference to the age-coefficient relation for this type of pipe and the effect of water quality upon rate of capacity loss.

The report also contains sections dealing with various remedial measures for reducing and preventing loss of capacity, including discussion of cement and bitumastic-enamel linings; methods of lining pipe in place; corrective treatment of the water carried; and pipe cleaning.

Certain other subjects not involved in the question of discharge coefficients of tar-coated cast-iron pipe, but falling within the general scope of the subject of "Pipe Line Friction Coefficients," have been presented in the form of appendices, in order that this additional information might be made readily available in a single report.

A summary of the report is given in Section I. A detailed discussion of coefficients for tar-coated cast-iron pipe and the effect of age and water quality upon coefficient values will be found in Section II. Data upon various methods for reducing capacity loss are included in Sections II to VIII, inclusive. Discussion of coefficient values for steel and concrete pipe, will be found in Appendices I and II, respectively; with the remaining data in the report, appearing in Appendices III to VI, inclusive.

The character and volume of the original data are such as to render prohibitive the cost of reproducing them in full in this report. In order to make them available to the profession, data that are not included in the printed report have been placed on file in the Engineering Societies' Library at 29 West 39 Street, New York, N. Y.

Precision. Mention should be made of the fact that the Committee has endeavored to compile *mass data of reasonable precision;* obviously, the widely varying conditions found, and the many factors involved, could not be generalized upon any other basis. Accordingly, while the collection of data was in no way restricted to sources affording "laboratory" precision, the material presented includes only such data as have been considered to fall within the limits of reasonable precision set by the Committee.

This policy applies particularly to the presentation of various "trend curves," which is the designation adopted for generalizing the age-coefficient relation. These *trend curves* have been presented only in cases for which numerous tests of reasonable accuracy were available.

Summary. Upon reference to Figure 1, page 241, it will be found that the actual value of the Williams-Hazen C, after 30 years of service, based upon average conditions in 19 cities for tar-coated cast-iron pipe having a weighted average diameter of 20.5 in. is 64; as compared with the predicted value in the Williams-Hazen Tables of 88. Otherwise expressed, even for these relatively large mains the value of C dropped to 88 after only 11 years of service, instead of after the predicted 30-year period.

The vast financial loss, resulting from rapid capacity reduction of pipe systems indicated by the data upon which this report is based, is a matter of major importance to the water works industry. It is believed of sufficient moment to warrant the determination in each system of the rate and cause of loss, as a basis for the adoption of the best preventive measures,

whether they are provision of permanent linings or corrective treatment of the supply.

Conclusions. In order that the conclusions upon the major subject of this report, namely, the age-coefficient relation of tar-coated cast-iron pipe, may be immediately brought to the attention of the reader, they follow herewith:

1. Capacity, rather than structural integrity, is usually the controlling factor in the useful "life" of cast-iron pipe.

2. While cast-iron water pipes are frequently credited with a life of from 50 to 100 years, in many instances the progressive decrease of carrying capacity cuts the actual useful life to a fraction of this period.

3. Data furnished to the Committee indicate that the average rate of capacity reduction is, in the majority of cities, and particularly for mains less than 16 in. in diameter, substantially greater than the rate indicated in the Williams-Hazen Tables for "average soft unfiltered river water."

4. The economic loss due to reduced carrying capacity is of sufficient importance to warrant the determination of capacity trends in each city.

5. Quality of water and its effect upon the relative rate of capacity loss with age constitute a factor in the comparison of alternate sources of supply.

6. Calcium carbonate, alkalinity, and carbon dioxide content are important factors in the quality of water as affecting the rate of capacity loss. Because of the inter-relation between alkalinity, carbon dioxide, and pH value, the latter determination, which is readily made, in turn shows a well defined relation to the rate of capacity loss.

7. Causes of capacity loss may be classified as:

(*a*) Tuberculation.

(*b*) Incrustation.

(*c*) Slime or fungus growths.

(*d*) Silting.

8. Selection of the most advantageous method for preventing capacity reduction necessitates consideration of the following local factors:

(*a*) The factors causing losses, *i.e.*, whether tuberculation, incrustation, etc.

(*b*) The relative rate of loss.

(*c*) The relative cost of available methods for eliminating or retarding such losses.

9. Available alternate methods for preventing or reducing capacity loss may include the use of permanent linings, corrective treatment, or use of pipe materials not subject to serious capacity loss.

10. The most advantageous method of recovering and making reasonably permanent the capacity of *existing* mains with low coefficient values may include cleaning followed by some method of lining in place.

Recommendations. The Committee makes the following recommendations:

1. That the NEW ENGLAND WATERWORKS ASSOCIATION consider the formation of a Continuing Committee, to coöperate, or to form a joint committee, with the American Water Works Association, in order to extend the scope of this report.

2. That an endeavor be made to select typical pipe lines representative of the more important classifications of conditions, types and sizes of pipe, and that such lines be periodically tested to provide adequate data for the information of the profession.

The Committee desires to record its appreciation of the coöperation of the officials, members, and associates in the water works field listed in Appendix VI who, by their contribution of data, have made the compilation of this report possible.

Respectfully submitted,

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SECTION I

SUMMARY OF REPORT

In order to bring immediately to the attention of the reader the scope and results of this investigation, a summary of the salient points covered is presented herewith. Details of the data upon which the conclusions have been based will be found on later pages under pertinent headings.

The Williams-Hazen formula has been used throughout this report for the determination of coefficient values, and all values of "C" presented refer to the Williams-Hazen coefficient as derived from the following formula:

$$v = C\, r^{0.63}\, s^{0.54}\, 0.001^{-0.04}$$

v = Velocity in feet per second
r = Hydraulic Radius in feet
s = Hydraulic slope in feet per foot
C = The Williams-Hazen Coefficient

In this report test results are frequently expressed directly in terms of the value of C, without translation into equivalent capacity. It is assumed that the reader is aware that capacity is directly proportional to the value of C, and that, for example, with slope and diameter fixed, a drop in the value of C from 130 to 65 involves an equivalent capacity loss of 50 per cent.

Coefficients of Tar-Coated Cast-Iron Pipe.

Values of C for New Pipe. A discussion of capacity loss requires a fundamentally important assumption, namely, a value of C for new pipe.

The following values of C have been adopted in this report for *new tar-coated cast-iron pipe:*

For supply and transmission mains 16 in. and larger in diameter..... C = 135
For distribution mains less than 16 in. in diameter, with allowance for tees, valves, bends, corporation cocks, or other specials involving friction losses .... C = 125

No fixed single value of C can cover the range in C which will be encountered even in the case of *new* pipe, and variations possibly approaching magnitudes 10 per cent. higher or lower than the values adopted by the Committee, may be found in extreme cases. Adoption of a fixed value was essential, however, and the Committee's values were based on the *average data* available to it.

Trend of Capacity Reduction with Age Given in the Williams-Hazen Tables. The most widely used basis for estimating the probable loss of capacity of tar-coated cast-iron pipe with age (other than the assumption that C = 100), is the age-coefficient relation shown in the column headings of the Williams-Hazen Tables, and reproduced in the form of curves on Figure 2, Page 252.

These *predicted* age-coefficient relations, or *trends* of C, accordingly form a convenient basis for comparison with the *actual trends* computed from the data submitted to the committee. They have been used in this manner throughout this report.

In the Williams-Hazen Tables, the value of C for average new pipe is assumed to be 130, and the predicted rate of coefficient drop *with average soft unfiltered water* is such as to reach, after a service period of 30 years, values of C varying from 75 to 91 for 4-in. and 60-in. pipe respectively. The equivalent predicted capacity losses are 42.3 and 30 per cent. for the respective sizes.

Actual Trend Curves in Various Cities. The compilation of data that will indicate the *actual trend of the age-coefficient relation* in various systems has been the major aim of the committee. To this end, a total of 473 tests in 19 different cities, the results of which have heretofore not been published, have been classified by the Committee and are presented in this report; generally in the form of *trend curves.*

These curves generalize data covering cases for which a considerable number of reasonably accurate tests were available. Data from numerous other sources were received and studied; but when the tests were limited in number or of questionable accuracy, no attempt was made to prepare generalizing curves.

It should be emphasized that all tests reported — except in a few instances that are specifically noted — represent *actual field tests,* and that the results accordingly include all incidental losses due to irregular line or grade and due to fittings or special castings.

The trend curves have been placed in two major classifications:

(1) Supply and transmission mains 16 in. and over in diameter.
(2) Distribution mains less than 16 in. in diameter.

These two major classifications were deemed necessary because greater loss of capacity including various minor sources of head loss, due to valves, tees, branches, corporation cocks and similar obstructions, are common in small distribution mains but do not occur in general in larger supply and transmission mains.

Further sub-classification has been made by bringing trend curves together according to type of treatment or source of supply, or according to general location or type of supply. These sub-classifications should not be over-emphasized, for as shown in Figure 9, page 269, they must be used with caution. In this figure, four separate trend curves are shown for different types of water supply. For all practical purposes these curves indicate the same rate of capacity loss. It is of interest to note that one of the supplies carries surface water, another well water, and the other two mixed well and surface waters. In no case is the water treated. The four supplies are widely scattered; they are situated in Connecticut, New York, Ohio and Arizona.

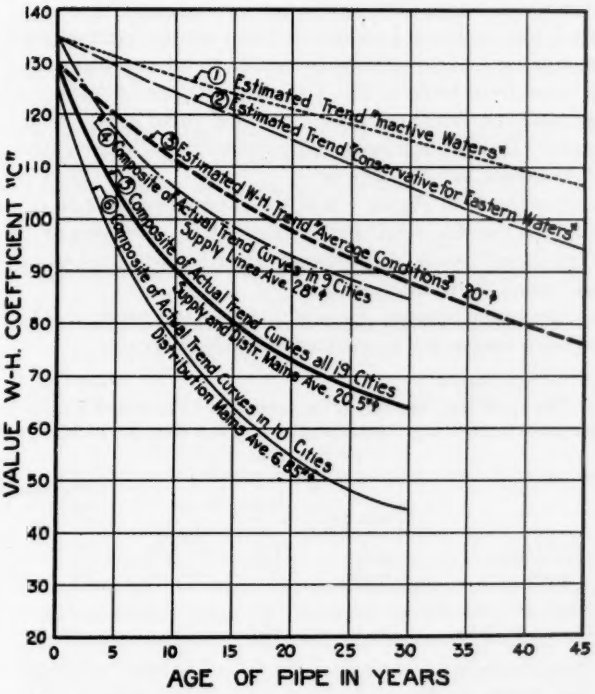

FIG. 1.— SUMMARY OF ESTIMATED AND ACTUAL TRENDS OF AGE-COEFFICIENT RELATION FOR TAR-COATED CAST-IRON PIPE.

Curves 1 *and* 2 are based on data for steel pipe (U. S. Dept. of Agriculture, Bull. 150, 1930).

Curve 3 is based on the Williams-Hazen Tables for average soft unfiltered river water.

Curve 4 is a composite for supply and transmission lines 16 in. or larger in diameter.

Curve 6 is a composite for distribution mains less than 16 in. in diameter.

Curve 5 is a composite of Curves 4 and 6. Composite curves are based on arithmetic averages.

A general numerical summary of the actual trend curves is given in Table 6, page 255, and the individual curves for each of the 19 supplies reported upon are reproduced in Figures 3 to 9, inclusive.

Three composite curves showing average actual trends, are represented in Figure 1. These curves are based on 473 tests in 19 systems, and accordingly summarize the data furnished to the Committee.

Figure 1 also includes 3 estimated trend curves, reproduced for purposes of comparison. Two of these estimated trends are based on data for steel pipe taken from Bulletin 150, U. S. Department of Agriculture. The third represents the Williams-Hazen predicted trend for 20-in. tar-coated cast-iron pipe. This size is substantially the same as the weighted average size for all 473 tests, namely, 20.5 in.

It is apparent from Figure 1 that the average actual rate of capacity loss, based upon the data available, is substantially in excess of any of the published predicted trends. This excess is particularly marked in the case of relatively small distribution mains.

The comparison between *actual* and *predicted* trends, based on these three composite curves, is summarized in Table 1.

TABLE 1.— SUMMARIZED COMPARISON OF ACTUAL AND PREDICTED VALUES OF THE WILLIAMS-HAZEN C FOR TAR-COATED CAST-IRON PIPE AFTER 30 YEARS OF SERVICE.

Origin of Composite Trend Curve	Average Pipe Diameter All Tests* (Inches)	Actual Trends.		Williams-Hazen Predicted Trends.	
		Value of C	Equivalent Capacity Loss (Per cent.)	Value of C	Equivalent Capacity Loss (Per cent.)
Average Trend Curves for Supply Lines in 9 Cities....	28.0	85	37	90	30.8
Average Trend Curves for Distribution Mains in 10 Cities.....	6.85	45	64	82	37
Average Trend Curves for all 19 Individual Trend Curves	20.5	63	51.5	88	32.3

* Weighted by number of tests of each size; length disregarded.

Summarizing the data furnished to the Committee, the following statements may be made:

1. The Williams-Hazen predicted trends are applicable primarily to large-diameter mains carrying relatively inactive water and do not represent *average* conditions.

2. The average actual capacity loss in 30 years is 51 per cent. as compared with a Williams-Hazen predicted loss of 32.3 per cent. In other words, the actual loss is 1.6 times the Williams-Hazen predicted loss.

3. In most cases new pipe exhibits a comparatively rapid rate of loss in the first years of service, followed by a diminishing rate of loss. As a result, the *actual* trend curves are generally found to have a slope which differs considerably from the more uniform slope of the Williams-Hazen predicted curves.

The Committee desires to stress the point that composite curves, such as those presented in Figure 1, portray only the *average data received during this investigation*, and that these curves must be interpreted and used with caution.

Quality of Supply and Its Effect upon Rate of Capacity Loss. Together with the compilation of data to determine actual rates of capacity loss which have developed in tar-coated cast-iron pipe in various water systems, information was obtained relative to the quality of the water carried in the mains tested.

The results of this comparison of quality and rate of loss, are shown in Figure 15, page 278. This diagram records the relation between pH value and total capacity loss in 30 years, for the systems for which data were available to the Committee.

The magnitude of the increased loss indicated in Figure 15 for supplies having low pH values, is summarized in Table 2.

TABLE 2.— SUMMARIZED EFFECT OF pH VALUES OF WATER CARRIED UPON CAPACITY LOSS AFTER 30 YEARS OF SERVICE.

pH Value of Supply.	Approximate Average Per Cent. Capacity Loss in 30 Years.
8.0	30
7.5	35
7.0	45
6.5	60
6.0	85

Alkalinity and carbon-dioxide have an important effect on rate of capacity loss. Because of the inter-relation between alkalinity, carbon-dioxide and pH, this effect may be measured against the pH value alone.

The inter-relation between alkalinity, carbon-dioxide and pH value is shown in Figure 14, page 277. A typical numerical example may be given as follows:

Water with an alkalinity of 10 p.p.m. will have a pH value of 7.3 when 1. p.p.m of CO_2 is present and a pH value of 6.3 when the CO_2 content is raised to 10 p.p.m.

Capacity Loss in Tar-Coated Cast-Iron Pipe Due to Special Causes other than Tuberculation. Certain cases covered by Committee data afford examples of capacity loss due to special causes. In some instances the resulting trends are quite similar to the rates caused by tuberculation. Among the special causes of loss are: Incrustation, due to the precipitation on the pipe either of the natural mineral content of the water or of lime after water treatment; slime or fungus growths; and silting.

Coefficient Values of Cement-Lined Pipe.

Development of the centrifugal method of applying cement lining to pipes has inevitably resulted in greatly increased use of this type of lining as a means for preventing capacity loss.

Available data upon values of C for cement-lined pipe are limited in scope and widely scattered in the literature. All data available to the Committee upon this subject have accordingly been collected in order that they may become more readily available. (See Table 8, page 290.)

The average value of C indicated by these data for *new* pipe, 4 to 24 in. in diameter with cement lining centrifugally applied, is as follows:

Williams-Hazen C based on nominal diameter.....134
Williams-Hazen C based on actual net diameter....150

The data also indicate that, at least for mains 24 in. or less in diameter the effect of lining thickness on diameter encroachment is sufficient to warrant considering values of C based both on *nominal* and *actual net* diameter.

A few tests were available for pipe lined with "natural" or "Rosendale" cement, not centrifugally applied. The pipes tested were 6 and 16 in. in diameter. The former was new pipe; the latter was pipe tested four times during a service period of from two months to ten years and seven months. No apparent loss with age was indicated by the consecutive tests of the 16-in. pipe. The value of C for this type of lining,— in terms of actual net diameter, which affords the best basis for comparison,— was found to be 136, as compared with a value of 150 for linings applied by the centrifugal method. This differential of fourteen points may, perhaps, be attributed largely to the difference in uniformity of interior surfaces obtainable by the two methods of lining.

Results of two tests on old-style cement-lined wrought-iron pipe 12 and 14 in. in diameter were also available. In both cases the value of C after 41 years of service was 104. The differential between this value and magnitudes of 150 and 136 for the types previously discussed, may be largely due to the difficulty (with the methods of manufacture available in that early period) of obtaining a uniform diameter free from undulations.

Available data relative to the value of cement lining in maintaining hydraulic capacity are extremely limited in scope. One line tested when new and again after six years of service showed no loss of capacity. Another line tested when new and after one, seven, and ten years of service also showed no tendency to decrease in carrying capacity with age. The value of C = 104 for the old-style cement-lined wrought-iron pipe after 41 years of service also indicates that cement lining can be credited with a sustained capacity not attainable with dip tar-coating.

Coefficient Values of Pipe with Bitumastic-Enamel Lining Centrifugally Applied.

As in the case of cement lining, the development of the centrifugal process for lining pipe with bitumastic enamel has resulted in greatly increased use of this type of lining as a means for controlling capacity loss.

Only limited data are available on coefficients for this type of lining. Results of *all of the tests* which have been conducted, together with a discussion of test methods, are presented on later pages of this report. (See Table 9, page 296.) Tests on 10-, 12-, and 20-in. cast-iron, and on 30-in. steel pipe are included.

The limited data available indicate that coefficient values based on nominal diameter, for *new* supply and transmission mains 16 in. in diameter and larger, with bitumastic-enamel lining, centrifugally applied, may vary from 145 to 160 with an average value of C = 155. These data also indicate that the value of C for distribution mains less than 16 in. in diameter, with this type of lining, may vary from 140 to 150 with an average of C = 145.

Bitumastic-enamel lining is ordinarily applied with a thickness of only $\frac{3}{32}$ in. Accordingly the encroachment on diameter is small as compared with other types of lining. The necessary increase in C, to offset this diameter encroachment, involves approximately 12 points for a 6-in. pipe and 3 points for a 16-in. pipe.

The first application of bitumastic enamel by the centrifugal method was made in 1931. Accordingly no data are available relative to the sustaining of hydraulic capacity with this type of lining. The longest service period reported is two years, and the results of this test indicate no loss.

The same material, applied by the hand-brush method, has been widely used for many years, and visual inspection of large pipe thus lined indicates that at least within periods of 16 years no apparent deterioration has occurred.

Application of Linings to Mains in Place.

Active interest in the subject of capacity loss during the last few years, has led to the development of several methods for reconditioning or lining existing mains *in place*, subsequent to cleaning.

Two methods have been devised in England for lining small-diameter mains. The "Eric" process deposits a bitumen lining electrically; the "Tate" process deposits a cement-mortar lining.

In this country, reconditioning of large-diameter pipe has already been carried on in pipes sufficiently large to permit a man to enter, clean the line carefully, and then apply a hot bituminous-enamel lining. Equipment has also recently been developed for the centrifugal application of cement lining in large-diameter pipe in place. No air is used as in the Cement-Gun method. The lining is whirled into place by a high-speed centrifugal jet. The method is at present limited to diameters 48 in. or larger.

A brief discussion of results of lining small-diameter mains by the "Tate" process will be found in Section VI. Details of this method, and of the two methods developed in this country for lining large pipe in place, were presented at the Convention of the American Water Works Association in Cincinnati in 1935.

Corrective Treatment.

In addition to the use of permanent pipe linings, chemical treatment of water for reduction of corrosion has been adopted in recent years to combat capacity loss.

In Section VII brief mention is made of some of the more important phases of this subject. Among them are the following:

(1) Water saturated with calcium carbonate is practically non-corrosive to iron.

(2) The pH value at which saturation equilibrium occurs, varies with the characteristics of the water treated.

(3) It is essential to maintain the treated water at or very near the saturation point, for super-saturation results in excessive deposits and under-saturation causes the destruction of needed protective films.

Lime, sodium hydroxide and soda ash are among the alkalies used to reduce corrosion. Lime is considerably cheaper than the sodium compounds, but for each part per million of carbon-dioxide converted by lime into calcium bicarbonate an increase of 1.138 p.p.m. in hardness occurs. It has been estimated that the cost of hardness is approximately 1c. per capita per year per part per million of hardness. In comparing the cost of various chemicals for corrective treatment, this indirect cost of lime should be taken into account.

Restoration of Capacity of Unlined Cast-Iron Mains by Cleaning.

The subject of cleaning cast-iron mains to restore capacity is definitely related to the problem of capacity loss. An attempt has, therefore, been made to summarize available data upon the two more important phases of this question: (1) immediate increase in coefficient value and consequent increase in capacity obtainable by cleaning; and (2) rate of capacity loss subsequent to cleaning; or otherwise expressed, maintenance of capacity after cleaning.

Data discussed on later pages indicate that cleaning will ordinarily restore the mains to approximately 85 per cent. of their original capacity. The average value of C in 24 tests (see Table 8, page 290) was 39 before and 104 after, cleaning. If it is assumed that the value of C for the new pipe was 125, the percentage of original capacity was 31 before and 83 after cleaning.

Maintenance of the relatively high capacity obtained by cleaning is subject to wide variations in individual cases. In some instances, particu-

larly in small mains, the results of cleaning are reported to last not more than 4 or 5 months. In other cases, the capacity is maintained at a reasonably high value for substantial periods of time. Experience in various places is described on later pages.

SUMMARY OF APPENDICES.

Certain subjects, while not directly concerned with the age-coefficient relation for tar-coated cast-iron pipe and with consequent capacity loss, are nevertheless involved in the general question of "pipe-line friction coefficients."

A discussion of data on these allied questions has therefore been included for purposes of reference in four Appendices. These are summarized below.

Coefficient Values of Steel Pipe. Discussion of coefficient values of steel pipe calls for definition of the several classes of steel pipe. The following classification by Scobey* provides a convenient standard for summarizing the values of C for various types of steel pipe when *new*.

Classification of Types of Steel Pipe (New Pipe).	ORDINARY VALUES OF THE WILLIAMS-HAZEN C.		
	Average.	Maximum.	Minimum.
Full Riveted	115	130	90
Girth Riveted	130	...	...
Continuous Interior	139	140	130
Spiral Riveted — Flow with laps	110	...	...
Spiral Riveted — Flow against laps	100	...	...
Corrugated Pipes	60	...	...

The higher values of C for steel pipe having a comparatively smooth interior are indicated in this tabulation and in more detailed tables presented in Appendix I.

Insufficient data are available to the Committee to establish trend curves showing the age-coefficient relation for steel pipe, excepting for three cases discussed later.

Coefficient Values of Concrete Pipe. Available data on concrete pipe indicate a wide range of C. There are instances of values of C as low as 85 and as high as 152. This wide range may be attributed not only to variations in the surface texture or roughness of the pipe but also to the relative uniformity of the pipe bore, or the presence or absence of undulations on the interior surface.

Obviously, particular care must be exercised in selecting values of C for concrete pipe. The average value of C for the best grade, new, large-diameter, pre-cast, reinforced-concrete pipe, carefully manufactured, may be assumed to approximate 150. Unless rigid metal forms, rich mix of concrete, careful curing and best workmanship throughout are employed, considerably lower values must be anticipated.

*Bulletin 150, U. S. Department of Agriculture.

In Appendix II, values of C for concrete pipe of different classes and different methods of manufacture are presented. These values are taken largely from a most commendable paper by Fred C. Scobey.*

Tests on concrete pipe after substantial periods of service indicate that under normal conditions the initial capacity is relatively permanent.

Various Tests Affording a Direct Comparison of Coefficient Values for Different Types of Pipe Interior. Several series of "laboratory type" tests have been conducted under conditions favoring unusual precision. These establish rather definitely the difference in coefficient values of *new* pipe with various types of interior. Several of these comparative tests are believed of sufficient interest to warrant including the results in this report. In Appendix III will be found the details of the tests summarized in Table 3.

TABLE 3.—SUMMARIZED COMPARISON OF COEFFICIENT VALUES FOR DIFFERENT TYPES OF PIPE INTERIOR.

Pipe Material	Nominal Diameter (Inches).	Williams-Hazen C		Remarks.
		Nominal Diameter.	Actual Net Diameter.	
Cast iron	8	132	...	Bell joints.
Steel	8	146	...	Bell joints.
Tar-coated cast iron	4, 6, 8	133	137	Average value of C for all sizes.
Cement-lined cast iron	4, 6, 8	133	150	
Cement-lined steel	12	127	147	—
Talbot-lined steel	12	133	157	—

Effect of Velocity on Values of the Williams-Hazen Coefficient. The basis for the development of the Williams-Hazen formula has been frequently discussed, particularly in relation to the question of the effect of varying velocities upon the values of C. Analysis of the data furnished the Committee indicates that except for special cases involving the necessity of extreme precision, and where accordingly unusual facilities are available for hydraulic tests, the effect of velocity on the value of C may be neglected.

* *Jour. Am. Water Works Assn.*, Jan. 1929, vol. 21.

SECTION II.

COEFFICIENTS OF TAR-COATED CAST-IRON PIPE.

With Particular Reference to Effect of Age Upon Coefficient Values.

Tar-coated cast-iron pipe has been more widely used in water works practice than any other type. Accordingly it is the first type selected for detailed discussion in this report.

Two major classifications as to size and service are made as follows:

(1) Supply and transmission mains, 16 in. in diameter and larger.
(2) Distribution mains less than 16 in. in diameter.

Relatively large supply or transmission mains, with straight alignment both as to line and grade, inevitably have somewhat higher coefficient values than small mains in distribution service. Tees for hydrants and branches, together with valves and corporation cocks cause a certain degree of turbulence which tends to reduce coefficient values in the latter type of mains. This difference in value applies to new as well as to old pipe and must be considered apart from the factors creating progressive capacity loss with age.

The adoption of reasonably accurate values of C for *new* tar-coated cast-iron pipe represents an important basic assumption which must be made prior to the consideration of loss of capacity with age. It has, therefore, been desirable in considering the coefficients of both new and old pipe to make these two general classifications as to size and service.

Coefficients of New Tar-Coated Cast Iron Pipe.

Coefficients of New Supply and Transmission Mains 16 in. in Diameter and Larger. The coefficient adopted in this report for *new tar-coated cast-iron pipe in supply or transmission mains 16 in. or larger in diameter,* is 135.

Results of 18 tests on pipe averaging 26.3 in. in diameter, and ranging from 16 to 48 in. in diameter, are shown on Table 4. The average coefficient found in these tests is 133. Inasmuch as several tests do not apply to strictly new pipe, but to pipe of one year's service, a second column is shown in Table 4, in which an allowance has been made for the normal first-year drop. This allowance is based on actual trend curves prepared for the cities involved. The resulting average of the adjusted coefficients is 135.

Further justification for the adoption of this value may be drawn from the fact that it lies between the general Williams-Hazen assumption of C = 140 for "very best cast-iron pipe laid perfectly straight and when new" and of C = 130 as "the value that can be fairly counted on for good new cast-iron pipe."

Coefficients of New Distribution Mains Less than 16 in. in Diameter. The coefficient value adopted in this report for *new tar-coated cast-iron pipe, less than 16 in. in diameter for mains in distribution service,* and subject to the additional losses introduced by valves, tees, and corporation cocks, is 125.

TABLE 4.— COEFFICIENTS OF NEW TAR-COATED CAST-IRON PIPE SUPPLY AND TRANSMISSION MAINS OVER 16 IN. IN DIAMETER.

AUTHORITY.	Age of Pipe, Years.	No. of Tests.	Diameter of Pipe, Inches.	VALUE OF WILLIAMS-HAZEN COEFFICIENT.		REMARKS.
				By Test.	Estimated New.	
Pitometer Co., Philadelphia, Pa.	1	..	16.0	130	136	
Pitometer Co., Philadelphia, Pa.	1	..	16.0	131	137	
Pitometer Co., Philadelphia, Pa.	New	..	16.0	117	117	
Pitometer Co., Toledo, O.	1	..	16.0	127	130	
Pitometer Co., Toledo, O.	1	..	16.0	133	136	
*Williams Hubbell and Fenkell	New	20	16.02	146	146	Well laid.
*Williams Hubbell and Fenkell	New	30	16.02	145	145	Well laid.
*Lampe	New	4	16.48	131	131	Coated Danzig main.
Pitometer Co., Cincinnati, O.	New	..	24.0	144	144	
Pitometer Co., Kansas City, Mo.	New	..	24.0	128	128	
Pitometer Co., Philadelphia, Pa.	1	..	24.0	130	136	
*Williams, Hubbell and Fenkell	New	30	29.96	140	140	Coated; straight; no specials.
Flinn, Weston and Bogert	1.27	..	36.0	133	138	Conduit No. 2, Rochester, N. Y.
Kuichling	New	2	36.0	129	129	Coated Rochester main.
Pitometer Co., Philadelphia, Pa.	New	..	36.0	134	134	
Pitometer Co., Philadelphia, Pa.	1	..	36.0	116	122	
Pitometer Co., Philadelphia, Pa.	1	..	48.0	132	138	
*Stearns	New	3	48.0	142	142	Rosemary siphon.
Average	.....	.....	26.3	133	135	

* From Williams-Hazen Tables, 1933 Edition, page 4.

The results of several tests on pipe from 4 to 8 in. in diameter are shown in Table 5. The average value of the two tests on lines actually in service in distribution systems is 130. Four tests on lines laid for test purposes on piers with absolutely straight line and grade and, hence, free from any of the special losses previously mentioned, show an average value, based on nominal diameters, of 133.

It is believed that a value of 125 represents a fair value under conditions normally existing in distribution systems, and this value has been adopted in this report.

Predicted Trend of Capacity Reduction with Age Given in Column Headings in Williams-Hazen Tables

The Williams-Hazen Tables are the most generally used source for computing pipe friction. The data on capacity trend with age set forth in these tables represent the only readily available information upon this this question. Accordingly, discussion of the Williams-Hazen age-coefficient relations, designated herein as "trends," is of importance in the consideration of the data compiled by the Committee and has therefore been used as a basis for comparison with *actual* trends.

The column headings in the Williams-Hazen Tables carry circles showing the "age in years at which, on an average, as nearly as we know, cast-iron pipe will reach the values given in the column underneath." In addition to this information a table* is shown in which the same estimated coefficients are designated for cast-iron pipe "with average soft unfiltered river water" at ages increasing from 0 to 100 years.

Table 5.— Coefficients of New Tar-Coated Cast-Iron Pipe in Distribution Mains Less than 16 in. in Diameter.

Authority.	Age of Pipe.	No. of Tests.	Diameter.		Value of William-Hazen Coefficient.		Remarks.
					Based On		
			Nominal Inches.	Actual Inches.	Nominal Diameter.	Actual Diameter.	
F. A. Barbour	New	..	6	.....	134	...	Distribution main in service.
F. A. Barbour	Few mos.	..	6	.....	125	...	
National Tube Co.	New	18	8	8.014	132	132	Test line on piers absolutely straight in line and grade.
M. L. Enger†	New	Many	4	3.96	132	135	
M. L. Enger†	New	Many	6	5.88	135	143	
M. L. Enger†	New	Many	8	7.97	132	134	
Average of Tests on New Pipe.....						131	

* Page 68, 1933 edition. †*Jour. Amer. Water Works Assn.*, Oct. 1927, p. 409 et seq.

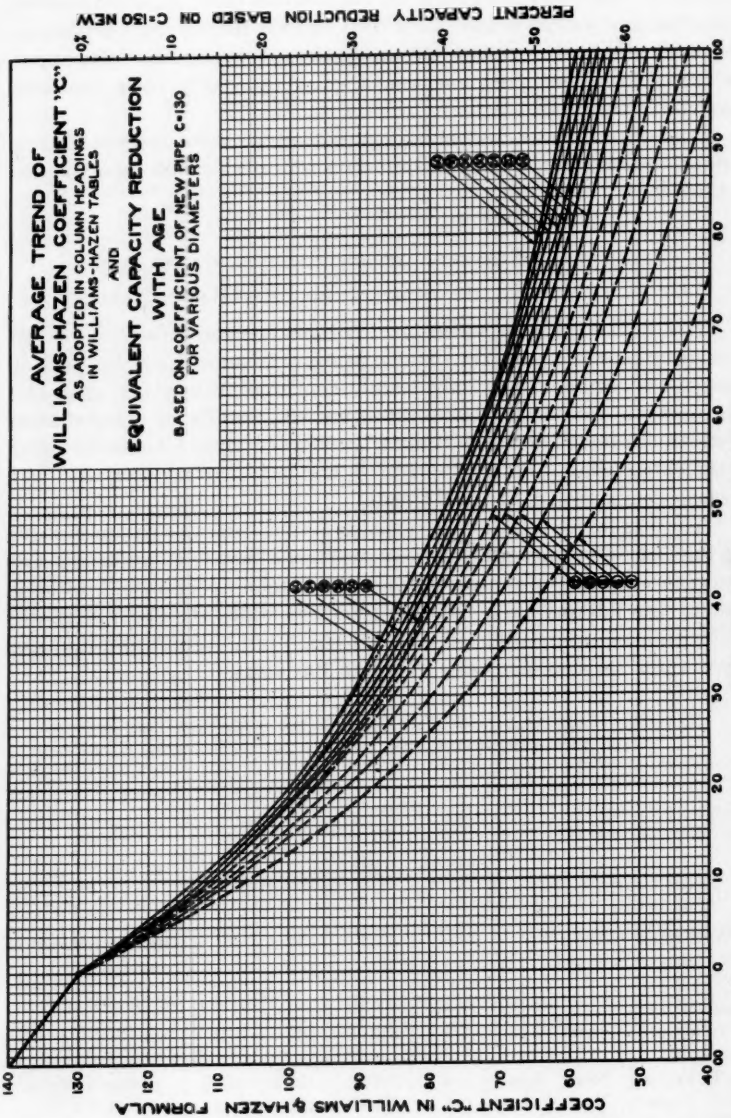
AVERAGE TREND OF
WILLIAMS-HAZEN COEFFICIENT "C"
AS ADOPTED IN COLUMN HEADINGS
IN WILLIAMS-HAZEN TABLES
AND
EQUIVALENT CAPACITY REDUCTION
WITH AGE
BASED ON COEFFICIENT OF NEW PIPE C=130
FOR VARIOUS DIAMETERS
PERCENT CAPACITY REDUCTION BASED ON C=130 NEW
COEFFICIENT "C" IN WILLIAMS & HAZEN FORMULA
AGE OF PIPE IN YEARS.

FIG. 2.

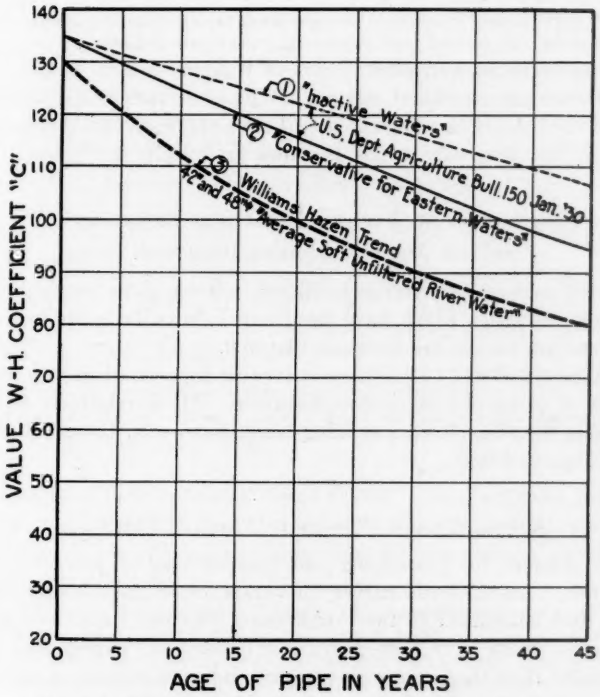

FIG. 3.— ESTIMATED TRENDS OF AGE-COEFFICIENT RELATION FOR TAR-COATED CAST-IRON AND STEEL PIPE BASED ON PUBLISHED DATA.

Basis for Williams-Hazen Predicted Trends. The following basis for the trends given in the Williams-Hazen Tables is sufficiently concise to warrant direct quotation:

> It must be understood that these values for estimating the decrease in coefficient value and consequent loss of capacity with age, are necessarily very rough approximations, based on the best data available, which are principally for soft and clear, but unfiltered river waters. Hard waters and lake waters will often attack the pipe less rapidly, and the figures must then be increased. *Sometimes they must be multiplied by two or more.** Other waters will corrode the pipes more rapidly than the average and for them the values will be reached more quickly than the figures indicate.

Curves Illustrating Estimated Trends in Williams-Hazen Tables. The Williams-Hazen age-coefficient relation for pipes of various diameters, as adopted in the column headings of their tables and based on the premises described in preceding paragraphs, is shown graphically in Figure 2.

Comparison of Various Published Estimates of the Age-Coefficient Relation.

Very few estimates of the age-coefficient relation have been published. Hence three estimates which have been found, have been set up in the form of trend curves and are shown in Figure 3.

It will be noted that two of these curves are for soft, or eastern, waters supposedly of comparatively active character. These relatively flat *estimated* trends therefore, form a striking comparison with the *actual* trends shown in Figures 4 to 9.

Actual Trend Curves in Various Cities.

Basis Adopted for Classifying and Summarizing of Data on Actual Trend Curves. Actual trend curves for various cities have been prepared from the data submitted to the Committee. The two major size-service classifications which have been previously defined as "supply and transmission mains 16-in. in diameter and larger" and as "distribution mains less than 16-in. in diameter" have been adhered to in summarizing these data.

It has also been deemed advantageous to make a secondary classification as shown in Table 6. This table also gives the average conditions for each of the geographical and quality divisions represented by the various trend curves. The data in Table 6, together with information for each of the individual curves comprising the composite curve for each district or group, are further illustrated in Figures 4 to 9, inclusive. The predicted Williams-Hazen trend for cast-iron pipe of comparable diameter is shown on each of the diagrams for purposes of comparison.

*Italics by Committee.

TABLE 6.— SUMMARY OF DATA ON ACTUAL TRENDS OF THE WILLIAMS-HAZEN C WITH AGE FOR TAR-COATED CAST-IRON PIPE.

CLASSIFICATION.	Figure No.	Reference Symbol.	No. of Trend Curves in Group.	Total No. of Tests in Group.	Weighted Average Diameter* Inches.	Average pH Value of Supplies.	AVERAGE PER CENTAGE CAPACITY LOSS IN 30 YEARS.	
							Actual.	Predicted By Williams-Hazen Trends. †
Supply and Transmission Mains 16 in. in Diameter and Larger.								
Mississippi River Basin	4	SM	4	132	26.1	8.8	31.8	31.3
Great Lakes Region	5	SL	3	68	26.7	7.6	37.8	31.2
Eastern Surface Supplies	6	SS	2	103	30.8	7.0	46.4	30.8
Distribution Mains Less than 16 in. in Diameter.								
Eastern Surface Supplies	7	DS	4	71	7.5	6.7	66.4	36.8
Long Island Well Waters	8	DL	2	30	6.5	6.2	72.8	38.0
Miscellaneous	9	DM	4	69	6.3	7.1	58.4	38.1
Totals	..	...	19	473	.....	.....	.....	.....
Arithmetic Averages	..	...	..	78.8	17.32	7.28	52.3	34.4

* Diameter for *each group* weighted by number of tests on each size. Length of test sections not considered.

† Based on value of new pipe of C = 130.

Summary of Data on Actual Trend Curves. To summarize briefly the information relative to the actual trend of capacity reduction with age, for tar-coated cast-iron pipe in the various systems investigated, the following statements may be made:

Large-diameter (average 26.4 in.) supply and transmission mains in the Mississippi River Basin and Great Lakes Region groups, carrying water ordinarily considered to be relatively inactive in character, show substantially as high rates of capacity loss as the Williams-Hazen predicted trends. Inasmuch as the latter trends were chosen to represent average conditions for soft unfiltered river water, the foregoing groups might well be expected to show considerably lower rates of loss. These conditions are illustrated in Figures 4 and 5.

Large-diameter (average 30.8 in.) supply mains carrying eastern surface supplies show trends resulting in a capacity loss after 30 years equal to 150 per cent. of the loss predicted by the Williams-Hazen trends (see Fig. 6).

Distribution mains with an average diameter of 7.5 in. carrying eastern surface waters (see Fig. 7) possessed an average value of C=42 after 30 years as compared with a value of 82 in the Williams-Hazen predicted trends. The actual capacity loss was accordingly 180 per cent. of the predicted loss.

Distribution mains with an average diameter of 6.5 in., carrying Long Island well waters (Fig. 8), also show a rapid loss of capacity, resulting in an average value of C=34 after 30 years of service, with an actual capacity loss of 73 per cent. as compared with a Williams-Hazen predicted loss of 38 per cent. for this period of service.

A group of distribution mains with an average diameter of 6.3 in., involving four systems in widely scattered locations from Connecticut to Arizona (Fig. 9) also show

much steeper trends than the Williams-Hazen predicted trends. The average actual capacity loss was found to be 153 per cent. of the estimated Williams-Hazen loss. These four supplies included surface water, ground water and mixed waters. The results demonstrate that no general classification can be made as to relative activity of waters, either upon the basis of *source of supply* (i.e. surface or well supply) *or upon the basis of geographical location.*

In conclusion it may be stated that under the most favorable conditions, with large-diameter pipe and relatively inactive water, the actual trend may be substantially in accord with the Williams-Hazen predicted trends.

Large-diameter mains carrying relatively active water, and all distribution mains called to the attention of the Committee show, regardless of water quality, substantially greater capacity loss with age than indicated by the predicted trends.

Analysis of Actual Trend Curves. Figures 4 to 9 inclusive illustrate a total of 19 *actual* trend curves developed from data in as many cities. A condensed description of the source of supply, methods of treatment, water quality, and other factors bearing upon the rate of capacity loss in each system will be found accompanying each diagram. These data afford a basis for selecting a trend curve for estimates which should be better applicable to any specific case than a composite trend .

Supply and Transmission Mains Carrying Primarily Filtered Surface Supplies with Lime and Iron Coagulation in the Mississippi River Basin.

Curve SM-1 (Figure 4). The actual trend of capacity loss indicated by Curve SM-1 is slightly less than the Williams-Hazen predicted loss for pipe of the same diameter, with an actual value of C after 30 years of 99 as compared with a predicted value of 89.

The type of treatment in effect during the greater portion of the life of the pipe tested may have retarded the rate of loss, provided the treatment was adequately controlled to prevent incrustation. Lime and ferrous sulphate were used for coagulation. This raised the pH value of the water from 7.3 to 8.7. The filtered water had a total alkalinity of 34.0 p.p.m., a phenolphthalein alkalinity of 5.0 p.p.m. and a total hardness of 115 p.p.m. of which 81 p.p.m. were permanent hardness. Free carbon dioxide was reported as never present in the treated water; the raw river-water content of 1.0 to 5.0 p.p.m. was entirely removed by the lime treatment.

Full treatment has been in effect since 1907. Since the friction tests were made in 1930–31, mains 24 years or less in age carried treated water only. Treatment includes:

(1) Preliminary sedimentation for 72 hours, assisted by alum coagulation for about 50 days per year.
(2) Coagulation with lime and ferrous sulphate.
(3) Six to ten hours of sedimentation.
(4) Rapid sand filtration.
(5) Disinfection at present with ammonia and chlorine.

Previous to 1907 raw river-water, subjected to a brief period of sedimentation in the case of a portion of the supply, was carried in the mains.

In developing the trend curve, only the tests on pipes 24 years or less in age were considered. The quality of the original untreated supply is not a factor, therefore.

In some of the tests on the older mains,— 45 to 55 years,— a decidedly greater loss of capacity is indicated, showing the effect of the quality of the original supply. This steeper trend of capacity loss in early years may be due in part to silting, before the introduction of filtration, and in part to the lower pH value of the raw river-water.

In general, it was found that pipe 50 years old had a coefficient value of 60, whereas the projected value, based on the trend with treated water, would not have fallen below 86 for pipe of this age. Pipe 50 years old carried untreated water for 26 years and treated water for the remaining 24 years.

Curve SM-2 (Figure 4). The trend of capacity loss indicated by curve SM-2 is substantially the same as for Curve SM-1; therefore, slightly less than the Williams-Hazen predicted trend. This is to be expected because of the similarity of both the raw and treated water in these two supplies; furthermore, because treatment was introduced at about the same time in each city and because the type of treatment is substantially the same.

As in the case of the supply represented by Curve SM-1, lime and ferrous sulphate were used for coagulation, and the pH value of the raw river water (varying from 7.4 to 8.2) was increased to an average value of 9.4 after treatment.

Treatment was adopted in 1909 and consists of:

(1) Preliminary plain sedimentation in a grit reservoir.
(2) Coagulation with lime and ferrous sulphate.
(3) Sedimentation for 20 hours.
(4) Rapid sand filtration, from 1915 to 1932.
(5) Disinfection by chlorination, since 1916.

Previous to 1909 raw river water was carried in the mains.

The tests were made in 1932. As none of the tests involved pipe more than 28 years old, the effects of the raw water had little influence on the values of C.

Curve SM-3 (Figure 4). The trend of capacity loss indicated by Curve SM-3 is slightly steeper than that of curves S-M1 and SM-2 and very similar to the Williams-Hazen predicted trend.

Treatment of the supply carried by the mains included in this system has been similar to that for the supplies basic to curves SM-1 and SM-2, involving the use of lime and iron. Somewhat greater quantities of lime have been used for softening purposes, and the resulting pH value is rather high. The average pH value of the raw river water is 7.8; that of the treated water has averaged 9.0. Under such conditions, the mains may at times have been subject to incrustation.

The friction tests were made in 1928. Filtration of part of the supply was instituted in 1915, and lime and ferrous sulphate were adopted for coagulation in 1904.

Because of many changes in treatment, it is not feasible to set forth the actual procedures for each year involved in the trend curves. In general, the following treatment was used:

(1) Preliminary plain sedimentation.
(2) Coagulation with lime and ferrous sulphate from 1904 to date.
(3) Sedimentation with aluminum sulphate as secondary coagulation for part of the supply since 1915.
(4) Rapid sand filtration for part of the supply started in 1915.
(5) Disinfection by both pre-and post-chlorination at present.

Curve SM-4 (Figure 4). The trend of capacity loss indicated by curve SM-4 is slightly greater than that of all other curves in this group. It is also slightly greater than the Williams-Hazen predicted trend. This may be attributed to the facts that rapid sand filtration had not been instituted up to the time the coefficient tests were made in 1926 and that the pH value of this supply is lower than that of the other supplies in this group.

The average pH value of the raw water was 8.0, the alkalinity 159 p.p.m., and the total hardness 225 p.p.m. The turbidity of the raw water varied from 100 to 20 000 p.p.m. and averaged 2 000 p.p.m.

Treatment of the water carried by the mains tested consisted of:

(1) Preliminary sedimentation for 4½ hours.
(2) Lime and alum coagulation with 1-minute mixing.
(3) Coagulation with 17.3 hours of detention.
(4) Chlorination.

Supply and Transmission Mains Carrying Primarily Filtered Surface Supplies with Alum Coagulation in the Great Lakes Region.

Curve SL-1 (Figure 5). The actual trend of capacity loss indicated by Curve SL-1 is slightly less than the predicted Williams-Hazen trend. The actual coefficient C at the end of thirty years is 100 as compared with a predicted value of 89. This relatively slow rate of capacity loss, in comparison with that of many other supplies investigated, may be attributed to the fact that the raw water in the river from which this supply is taken, is relatively inactive. It has a pH value of 8.3, an alkalinity of 83 p.p.m., a CO_2 content of 0, and a hardness of 97 p.p.m.

This supply has been filtered since 1924. The tests were run in 1928. Inasmuch as the tests deal with pipe averaging 45 years of service, filtered water had little bearing on the trend of capacity loss.

The tendency of the present method of treatment, which includes the use of alum, is to reduce the pH value from 8.3 to 7.6 with a coincident development of 3 p.p.m. of CO_2. It is not improbable, therefore, that the trend of capacity reduction will be steeper in the future when the change in quality introduced by filtration has had time to make itself felt.

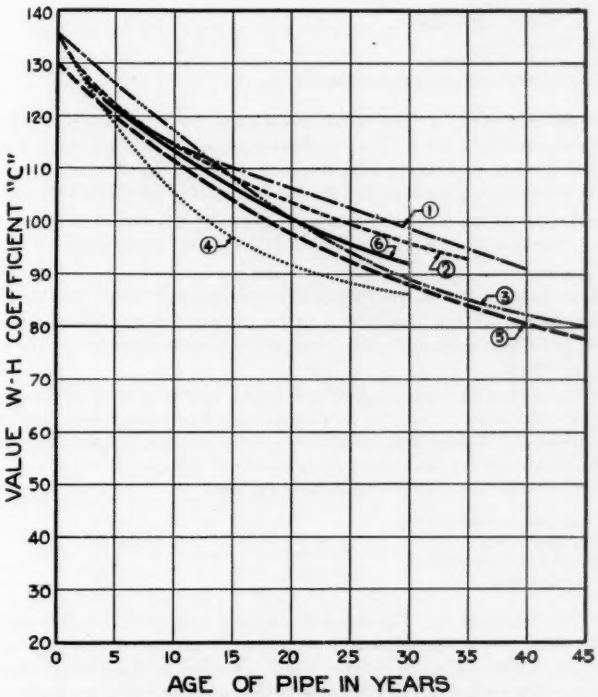

FIG. 4.— ACTUAL TRENDS OF AGE-COEFFICIENT RELATION FOR TAR-COATED CAST-IRON SUPPLY AND TRANSMISSION MAINS IN THE MISSISSIPPI RIVER BASIN.

Primarily Filtered Surface-water Supplies Coagulated with Iron and Lime.

Curve No.	River Source.	Weighted Average Diameter (Inches).	No. of Tests	pH Value.	Percentage Capacity Loss in 30 Years.
SM-1	Ohio	25.5	33	8.7	26.6
SM-2	Mississippi	28.1	55	9.4	29.0
SM-3	Mississippi	21.0	13	9.0	34.0
SM-4	Missouri	25.4	31	8.2	36.3
5*	....	24.0	..	....	31.5
6†	....	26.1	132	8.8	31.8

* Williams-Hazen estimated trend, new C = 130.
† Composite of curves 1 to 4.

Up to January 1924, raw river-water was used exclusively. As a result, only pipe less than four years old carried filtered water exclusively. No tests were conducted on pipe of this limited age.

The treatment in effect from 1924 to date, has been:

(1) Pre-chlorination.
(2) Coagulation with alum.
(3) Sedimentation.
(4) Rapid sand filtration.
(5) Post-chlorination with ammoniation.

Curve SL-2 (Figure 5). The actual trend curve SL-2 substantially follows the Williams-Hazen predicted trend. The coefficients are approximately ten points lower than for Curve SL-1 at equal ages. This, no doubt, is due to the effect of filtration after coagulation by alum during a substantial portion of the life of the mains tested.

The pH value of the raw water was approximately 8.1, that of the treated water averaged 7.5. The lake water carried no free CO_2; the treated water averaged 1.6 p.p.m., due to use of alum.

Tests on mains carrying this supply were conducted in 1930. Previous to 1911 no treatment existed. From 1911 to 1918 a portion of the supply was filtered, the balance of the supply receiving chlorination only. From 1925 to date the entire supply has been filtered and chlorinated.

The pipes upon which the trend curve is based, vary from 5 to 57 years in age. Hence they were subjected to water of varying quality. In general, it may be stated that the effect of treatment in increasing the rate of capacity loss, has been somewhat modified over the period of service by the use of both raw and mixed water.

The type of treatment in effect since 1918 has been:

(1) Coagulation with alum.
(2) Sedimentation.
(3) Rapid sand filtration.
(4) Chlorination.

Curve SL-3 (Figure 5). The trend of capacity loss of Curve SL-3 is substantially greater than that of the other two curves in this group. It is also considerably greater than the Williams-Hazen predicted trend. This may be due primarily to the fact that this supply is not taken directly from the Great Lakes, but from a tributary stream. Either the water quality, or the effects of treatment, result in a greater rate of capacity loss than in the case of Great Lakes water.

Treatment was introduced in this supply in 1910. The friction tests were conducted in 1926. The mains upon which this trend curve is based have carried only filtered water throughout their entire service, as only two tests were available on lines more than 15 years old.

Hypo-chlorite of lime was applied to the water from 1910 to 1917, and chlorination was introduced in 1917. A change to pre-chlorination was made in 1934. Iron and lime were used from 1910 to 1919 and alum and lime from 1919 to date.

The present treatment includes:

(1) Pre-chlorination.
(2) Coagulation with alum and lime.
(3) Sedimentation.
(4) Taste removal by activated carbon.
(5) Rapid sand filtration.
(6) Post-chlorination.
(7) Lime treatment for pH regulation.

Such limited data as are available on quality, indicate that treatment has little effect on the pH value. Both raw and treated water show a pH value of 7.8.

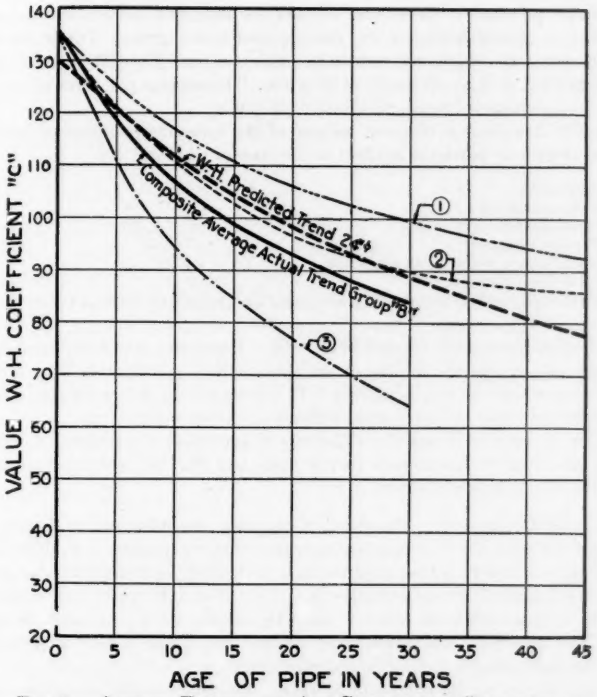

FIG. 5.— ACTUAL TRENDS OF AGE-COEFFICIENT RELATION FOR TAR-COATED CAST-IRON SUPPLY AND TRANSMISSION MAINS IN THE GREAT LAKES REGION.

Primarily Filtered Surface-water Supplies Coagulated with Alum.

Curve No.	Source of Supply.	Weighted Average Diameter (Inches).	No. of Tests.	pH Value.	Percentage Capacity Loss in 30 Years.
SL-1	Great Lakes	25.8	12	8.1	26.0
SL-2	Great Lakes	30.7	37	7.5	33.3
SL-3	Tributary Stream	19.2	19	7.8	52.6
4*	.....	24.0	..	..	31.5
5†	.....	26.7	68	7.6	37.8

* Williams-Hazen estimated trend, new C = 130.
† Composite of curves 1 to 3.

Supply and Transmission Mains — Eastern Surface Supplies.

Curve SS-1 (Figure 6). The actual trend of capacity loss indicated by Curve SS-1 is considerably greater than the Williams-Hazen predicted trend for pipe of the same diameter. This is particularly true for periods up to 20 years of age, when the actual value of C was 84 as compared with a predicted value of C = 99.

The water supplied to the system was derived from two independent sources, but the difference in characteristics of the two supplies is not great. The water may be generally classified as a fairly active eastern surface water. The pH value of the river water averaged 7.2, with an alkalinity of 37 p.p.m. The average pH value of the treated water was 7.1 accompanied by an alkalinity of 35 p.p.m.

Complete treatment is required because of the excessive pollution of the supply. The various treatment processes in effect at the present time are:

(1) Screening.
(2) Sedimentation.
(3) Coagulation with alum.
(4) Pre-chlorination.
(5) Preliminary rapid sand filtration.
(6) Slow sand filtration.
(7) Post-chlorination assisted by ammonia and hydrated lime at times.

The friction tests were conducted in 1926. Treatment was introduced in 1902. At this time only 1 per cent. of the entire consumption was filtered. The volume of water filtered increased each year until in 1912 it included the entire supply. The trend curve, therefore, is based primarily on the effects of filtered water.

A group of tests on mains 45 to 75 years of age shows a considerably lower rate of capacity loss than for more recent mains, indicating that the raw water in the early history of the supply was less active.

Curve SS-2 (Figure 6). The trend of capacity loss indicated by Curve SS-2 is markedly greater than the Williams-Hazen predicted trend for pipe of similar diameter. The actual value of C is 68 at the end of 30 years, instead of the predicted value of C = 90

This trend should be representative of fairly active, soft, untreated, eastern river waters. The average pH value was 6.9, the CO_2 content 2.0 p.p.m., and the hardness 30 p.p.m. The tests upon which this curve is based were made in 1927, and this supply has never received treatment other than chlorination.

The age of pipe varied from 6 to 58 years. Inasmuch as the source has not been changed, and treatment has not been introduced, an unusually good opportunity is afforded for consideration of the quality of supply in relation to its effect upon rate of capacity loss.

Distribution Mains — Eastern Surface Waters.

Curve DS-1 (Figure 7). The trend of capacity loss indicated by Curve DS-1, while lower than that of the others in this group, is far steeper than the Williams-Hazen predicted trend for pipe of similar diameter. The actual value of C is 57 after 30 years as compared with a predicted value of 82.

The friction tests on this supply were conducted in 1928. Filtration was introduced in 1902. Pipe having 26 years or less in age, therefore, carried filter water only.

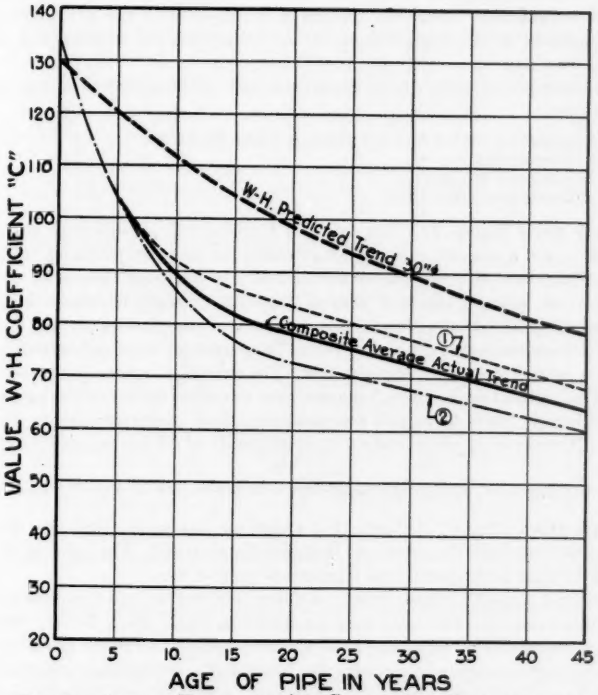

FIG. 6.— ACTUAL TRENDS OF AGE-COEFFICIENT RELATION FOR TAR-COATED CAST-IRON SUPPLY AND TRANSMISSION MAINS IN EASTERN SURFACE-WATER SUPPLIES.

Curve No.	Source of Supply.	Weighted Average Diameter (Inches).	No. of Tests.	pH Values.	Percentage Capacity Loss in 30 Years.
SS-1	Rivers	31.4	87	7.1	42.3
SS-2	Rivers	27.5	16	6.9	50.0
3*	....	30	..	..	30.8
4†	....	30.8	103	7.0	46.4

* Williams-Hazen estimated trend, new C = 130.
† Composite of curves 1 and 2.

Thirteen tests were conducted on pipe 26 to 42 years old. A somewhat lower trend of capacity loss is indicated in the earlier years while raw river-water was carried.

The use of untreated and treated water is reflected in the first portion of the curve, covering 0 to 25 years, being much steeper than the remainder for the following 15 years of service. The increased rate of loss after filtration began may be attributed to the use of alum in coagulation. Treatment results in a reduction of the pH value from 6.9 to 6.5, an increase in CO_2 content from 6.0 to 11.0 p.p.m., and a decrease in alkalinity from 35 to 24 p.p.m.

The treatment in effect during the greater part of the service period of the mains tested, includes:

(1) Coagulation with 0.5 to 2.5 grains of alum per gallon.
(2) Sedimentation.
(3) Rapid sand filtration.
(4) Chlorination, since 1910.

Curve DS-2 (Figure 7). The trend of Curve DS-2 is somewhat steeper than that of DS-1, and, again, substantially greater than the predicted Williams-Hazen trend. The actual value of C after 30 years of service is 47; the predicted value is 83.

The water, which is obtained from an impounded stream, has never been filtered. During the six years preceding the friction tests, a new source of supply was introduced, and the pH value has been adjusted by lime. These changes have undoubtedly affected, to a certain extent, the rate of capacity loss. The change in quality is so recent for the pipe involved in most of the tests, however, that the effect should not be marked. The trend, accordingly, should be quite representative of an untreated eastern river-water having a pH value of approximately 6.8, an alkalinity of 24 p.p.m., and a hardness of 41 p.p.m.

Prior to filtration, silting may have been a factor in rate of capacity loss.

Curve DS-3 (Figure 7). Curve DS-3 shows an exceedingly high rate of capacity loss in comparison with the predicted Williams-Hazen trend. The value of C is 43 at the end of 30 years as compared with a predicted value of 85.

The water carried by these mains has never been treated and two different sources of supply are involved. The tests were conducted in 1933. From 1887 to 1898, water was obtained from driven wells and a filter gallery adjacent to a river. Beginning in 1898 an untreated surface supply from rivers was introduced. Accordingly, pipes 35 years or less in age have, throughout their period of service, carried the new surface supply; pipes of greater age carried surface water for 35 years and prior to that ground water.

The age of most of the mains tested was less than 35 years and the existing surface supply undoubtedly dominated the rate of capacity reduction.

Curve DS-4 (Figure 7). The trend of capacity loss shown in Curve DS-4 is extremely high. The actual value of C is 20 after thirty years, instead of the Williams-Hazen predicted value of 83. The trend is steeper than for any of the other "eastern surface supplies."

The extremely high capacity loss in this supply may be due to the very low pH value of the supply and the tendency of filtration to make the water more aggressive.

The treatment in effect up to the time of these tests consisted of:

(1) Coagulation with alum.
(2) Sedimentation.
(3) Rapid sand filtration.
(4) Application of lime and chlorine.

The tests were conducted in 1927 and throughout the life of the pipe tested, treated water was carried exclusively.

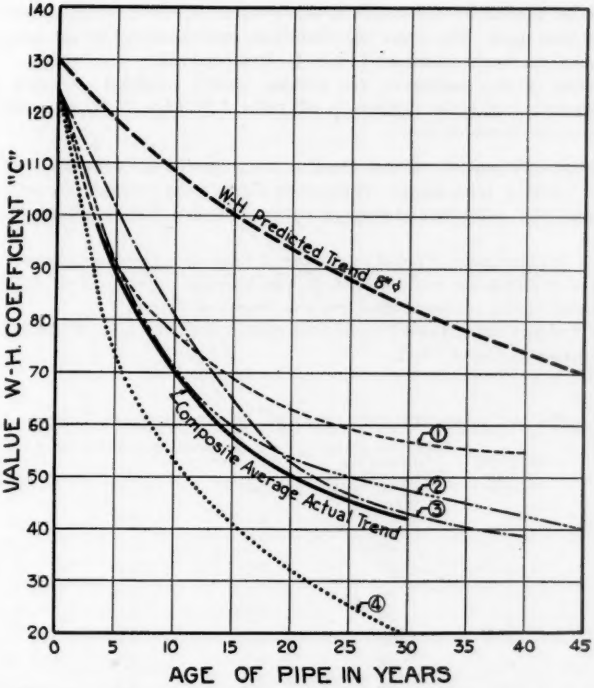

FIG. 7.— ACTUAL TRENDS OF AGE-COEFFICIENT RELATION FOR TAR-COATED CAST-IRON DISTRIBUTION MAINS IN EASTERN SURFACE-WATER SUPPLIES.

Curve No.	Source of Supply.	Weighted Average Diameter (Inches).	No. of Tests.	pH Value.	Percentage Capacity Loss in 30 Years.
DS-1	River	6.9	33	6.5	53.6
DS-2	River	7.8	27	6.8	61.6
DS-3	River	9.7	7	6.9	64.8
DS-4	River	7.0	4	6.6	84.0
5*	.....	8.0	..	...	36.1
6†	.....	7.5	71	6.7	66.4

* Williams-Hazen estimated trend, new C = 130.
† Composite of curves 1 to 4.

Distribution Mains for Long Island Well Waters

Curve DL-1 (Figure 8). Curve DL-1 has a very steep trend of capacity loss. It reaches a value of C = 37 in 30 years, as compared with the Williams-Hazen predicted value of 81.

The water carried by the mains in this system is derived entirely from wells. Two sources were used. The larger one, furnishing approximately 65 per cent. of the entire consumption, was provided with filters for iron removal.

The water is very aggressive, the average quality weighted according to the volume drawn from each of the supplies, is: pH value, 5.96; CO_2, 17.2 p.p.m.; alkalinity, 8.6 p.p.m., and, hardness, 30 p.p.m.

Curve DL-2 (Figure 8). Curve DL-2 is a composite curve based on 11 tests in 9 different towns on Long Island. As shown in Figure 8 the water is very active, with an actual value of C = 31 after 30 years as compared with a Williams-Hazen predicted value of 80.

Four of the tests were affected by the use of lime for corrective treatment. With only one test available for each system, it was believed impractical to develop the individual trend curves. A composite curve was, therefore, drawn.

Table 7 shows the indicated trend and related data for each of the individual supplies comprised in Curve DL-2.

TABLE 7.— CHARACTERISTICS OF LONG ISLAND SUPPLIES TESTED.

Test No.	Diameter of Pipe (Inches).	Estimated Actual Value of the Williams-Hazen C After 30 Years of Service.	Average Quality of Supply. pH Value.	CO_2 p.p.m.	Hardness p.p.m.
1	12	65	6.1	12.0	21.8
2	6	43	6.1	12.0	21.8
2a	8	67	6.1	12.0	21.8
3	6	50	7.3*	2.6	41.3
3a	6	54	7.3*	2.6	41.3
4	4	32	7.3*	2.6	41.3
5	4	36	6.5	5.4	16.3
6	6	22	5.8	8.5	11.9
7	4	31	5.8	8.5	11.9
8	4	20	5.8	8.5	11.9
9	6	70	6.8*	3.0	22.0
Average	6.0	44.5	6.45	7.0	23.9
Average for Systems Involving Corrective Treatment.					
	5.5	51	7.2	2.7	36.5
Average for Systems Not Using Corrective Treatment.					
	6.3	40	6.0	9.6	16.8

* Lime used to reduce corrosion.

Inasmuch as corrective treatment has been practiced only during an indefinite and limited time, the difference in loss of capacity of supplies using such treatment as compared with supplies delivering raw water is naturally not so marked as would be expected by a comparison of quality as recorded in Table 7. Nevertheless, Curve DL-2 has been affected to some extent by the corrective treatment practiced.

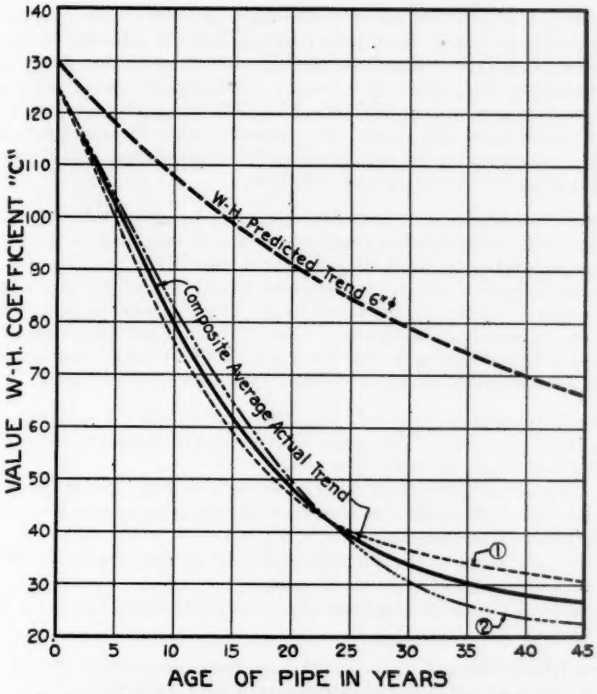

FIG. 8.— ACTUAL TRENDS OF AGE-COEFFICIENT RELATION FOR TAR-COATED CAST-IRON DISTRIBUTION MAINS CARRYING LONG ISLAND WELL WATERS.

Curve No.	Source of Supply.	Weighted Average Diameter (Inches).	No. of Tests.	pH Value.	Percentage Capacity Loss in 30 Years.
DL-1	Wells	6.74	19	5.96	70.4
DL-2‡	Wells	6.0	11	6.45	76.0
3*	....	6.0	..	...	38.5
4†	....	6.5	30	6.2	72.8

* Williams-Hazen estimated trend, new C = 130.
† Composite of curves 1 and 2.
‡ Composite of tests in 9 towns with pH value of water varying from 5.8 to 6.5 without corrective treatment. Two supplies, after lime treatment, showed pH values of 6.8 and 7.3.

Distribution Mains — Miscellaneous Supplies.

Curve DM-1 (Figure 9). Curve DM-1 exhibits a fairly steep trend of capacity loss, reaching an actual value of C = 60 after 30 years, as compared with a Williams-Hazen predicted value of 80.

This curve is of particular interest in revealing a high rate of capacity loss for pipes carrying a western well water which has a relatively high pH value and hardness. The curve drawn represents the average of two series of observations for two parts of a system, each carrying water from independent sources. Both supplies carry fairly hard raw untreated ground-waters, with a pH value of 7.7. The hardness of one supply was 240 p.p.m.; that of the other 108 p.p.m. The values of C after 30 years are 66.5 and 53 respectively. Analysis of the two original curves indicates the effect of hard water, other factors being equal, on rate of capacity reduction.

Curve DM-2 (Figure 9). Curve DM-2 is drawn for an untreated eastern surface water. A high rate of capacity loss developed, with an actual value of C = 52 after 30 years as compared with a Williams-Hazen predicted value of 78.

Information relative to water quality is not available. The pH value is estimated at approximately 6.7 and the hardness at 16 p.p.m. That this water produced practically the same rate of loss with age as is given by Curve DM-1, is of particular interest because of the widely differing conditions. One water is a hard (174 p.p.m.) western (Arizona) well water, the other a soft (16 p.p.m.) eastern (Connecticut) surface water.

Curve DM-3 (Figure 9). Curve DM-3 shows practically the same rate of loss as do Curves DM-1 and DM-2. The actual value of C after 30 years is 49, as compared with the Williams-Hazen predicted value of 82.

The water carried by these mains varied widely in quality. In early years the supply was taken entirely from wells; in later years, an increasing amount of surface water was obtained from an auxiliary supply.

The tests were conducted in 1911, and no data are available for the old well supply, which is now abandoned, or for the mixed supply.

The quality of the surface water was: pH value 8.0; alkalinity, 115 p.p.m.; and hardness 188 p.p.m.

Curve DM-4 (Figure 9). Curve DM-4 reaches a value of C = 46 after 30 years of service as compared with a Williams-Hazen predicted value of 80.

Two different sources supplied the mains. During the 14 years preceding the tests water was drawn from both a mixed well and surface supply (No. 1) and a surface supply (No. 2). Prior to this period, the water was taken exclusively from the mixed well and surface supply (No. 1).

The mixed supply (No. 1) had an average pH value of 6.8 and a hardness of 67 p.p.m. The surface supply (No. 2), had a pH value of 6.7 and a hardness of 20 p.p.m. The tests were conducted from 1929–1933.

The trend coincides substantially with the three other trends in this group. It possesses slightly lower values of C after 15 years of service, than in the case of Curves DM-1, 2, and 3.

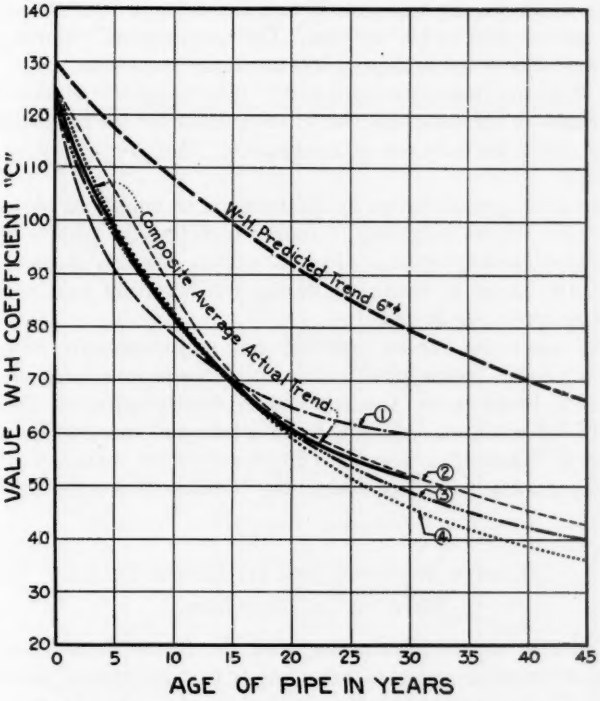

FIG. 9.— ACTUAL TRENDS OF AGE-COEFFICIENT RELATION FOR TAR-COATED CAST-IRON DISTRIBUTION MAINS.

Miscellaneous supplies of widely varying character and location.

Curve No.	Source of Supply.	Weighted Average Diameter (Inches).	No. of Tests.	pH Value.	Percentage Capacity Loss in 30 Years.
DM-1	Wells–Ariz.	6.0	7	7.7	52.0
DM-2	Surface–Conn.	5.2	5	6.7	57.6
DM-3	Mixed–Ohio	7.4	13	..	60.0
DM-4	Mixed–N. Y.	6.2	44	6.8	63.2
5*	.....	6.0	..	..	38.5
6†	.....	6.3	69	7.1	52.3

* Williams-Hazen estimated trend, new C = 130.
† Composite of curves 1 to 4.

Examples of Developing Actual Trend Curves.

The method employed in developing the trend curves shown in this report is illustrated in Figures 10–12. Each test which gave a value of C for a pipe of known age was plotted with the value of C as the ordinate, and the age in years as the abscissa. The trend curves,— shown as full lines,— were then fitted to these points as closely as possible.

The Williams-Hazen predicted curve "for average soft unfiltered river water," based on the same diameter as the average for the particular tests, was then added for purposes of comparison. They are shown as heavy dashed lines.

In the development of some of the trend curves, variations encountered necessitated a certain weighting of results in fitting the curves. Typical cases include diameter variations from 4 to 60 in., the introduction of new supplies and change in treatment during the relatively long periods of service considered (40–50 years).

In all cases the curves, although not mathematically precise, are believed to present trends which justify their careful consideration in connection with problems of capacity loss in similar systems. The small amount of tuberculation that will cause substantial capacity loss is well illustrated by Figure 13, a view of the interior of a 20-in. main at Lexington, Ky., handling a filtered surface water. The Williams-Hazen C for this main was 90.

Quality of Supply and Its Effect Upon Rate of Capacity Loss.

In order to obtain information upon the factors causing the wide variations in trends, or rate of capacity loss, in various systems, information has been collected relative to water quality.

A comparison of water quality in terms of the pH value and percentage capacity loss of pipes in 30 years, is presented in Figure 15, page 278. Results are included for 32 supplies for which data were available to the Committee. There is marked correlation between the two variables. Figure 15 may serve as a basis for preliminary estimates of the relative rate of capacity loss in supplies for which the pH value is known. Determination of the pH value is a simple, rapid procedure.

Information has also been compiled on the source of supply, methods of water treatment and quality attributes of the water carried by the mains, other than the pH value.

The trend curves showing the coefficient-age relation cover substantial periods of 30 to 40 years; in some cases data were available as far back as 80 years. In some cases new supplies have been developed; in others treatment has been introduced; and in still others new methods of treatment have been adopted. The art of water treatment has advanced markedly

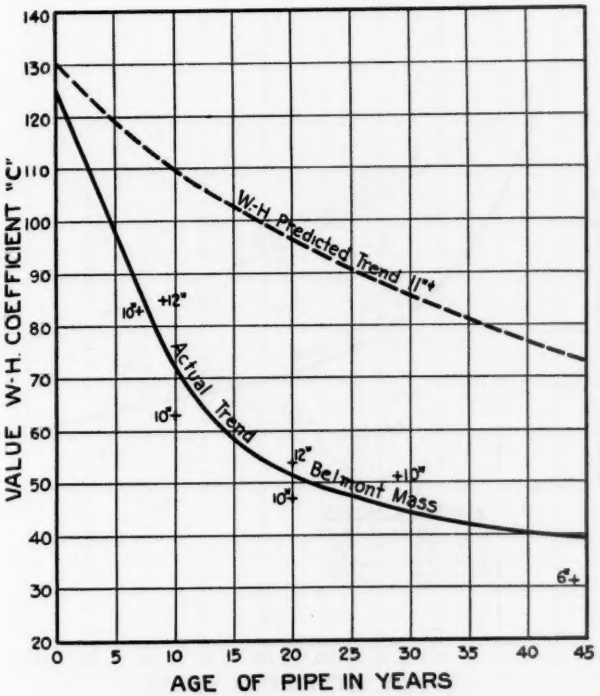

FIG. 10.— EXAMPLE OF DEVELOPING TREND CURVE FOR DISTRIBUTION MAINS.

Curve DS-2, Figure 7. Size of pipe is indicated for each point.

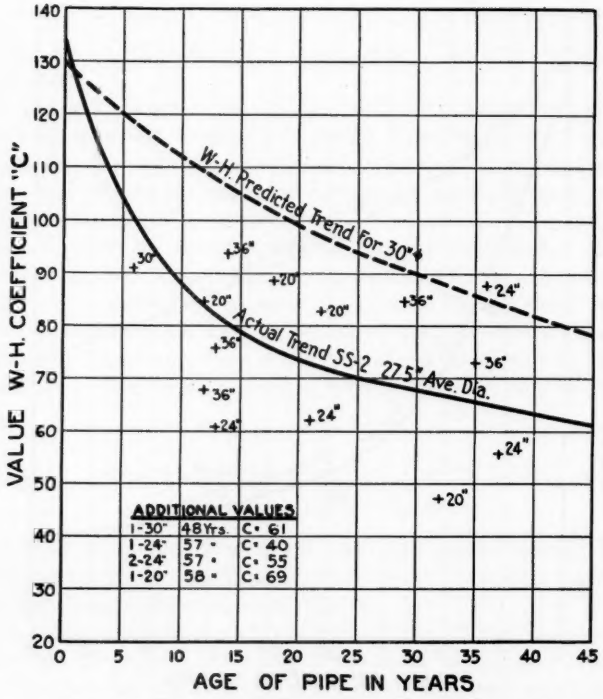
VALUE W-H. COEFFICIENT "C"
AGE OF PIPE IN YEARS
W-H. Predicted Trend For 30"ϕ
Actual Trend SS-2 27.5" Ave. Dia.
ADDITIONAL VALUES
1-30" 48 Yrs. C. 61
1-24" 57 " C. 40
2-24" 57 " C. 55
1-20" 58 " C. 69

FIG. 11.— EXAMPLE OF DEVELOPING TREND CURVE FOR SUPPLY AND TRANSMISSION MAINS.

Curve SS-2, Figure 6. Size of pipe is indicated for each point.

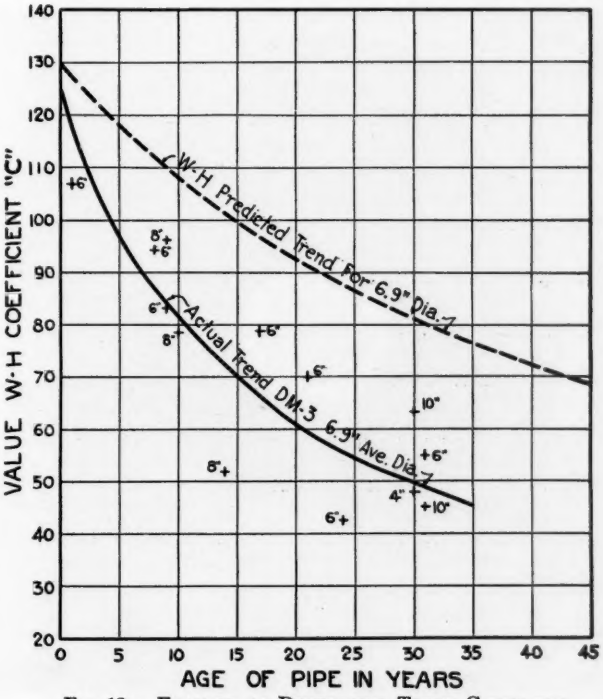

FIG. 12.— EXAMPLE OF DEVELOPING TREND CURVE FOR DISTRIBUTION MAINS.

Curve DM-3, Figure 9. Size of pipe is indicated for each point.

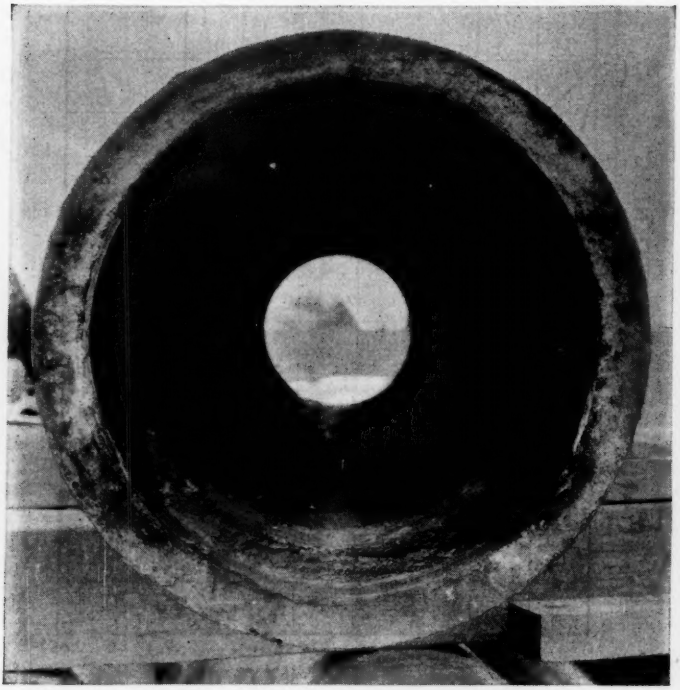

FIG. 13.—20-IN. MAIN AT LEXINGTON, KY., HANDLING FILTERED SURFACE WATER.
Williams-Hazen C = 90.

during the past 30 years, and methods of analysis and types of tests have also changed.

Except for the larger cities, records of water quality extending over 30 years are scarce. Hence it is impossible to arrive at a definite formula or mathematically precise basis for the effect of water quality upon relative rate of capacity loss.

The subject of corrosion is broad and varied. Its details fall outside the scope of this report. The importance of corrosion, however, particularly as it is related to the most common form of capacity loss,— namely tuberculation,— suggested a study of such data as were available, in order to provide some basis for general discussion of the more salient points involved.

The following paragraphs, therefore, must be considered a limited statement of some of the more common theories and relations. They are presented solely as a basis for general consideration of the problem and are subject to many qualifications for specific cases.

General Comments. Among causes of corrosion or tuberculation frequently considered are the following:

Dissolved oxygen content of the water.
Carbon dioxide content and acidity of the water.
Electro-chemical action between pipe and water.
Tendency of iron to dissolve and reprecipitate.
Building of soft nodules by "iron" bacteria.

The following facts relative to the rôle of calcium carbonate in water, particularly in connection with corrective treatment for corrosion reduction, were established some 15 years ago.

Water saturated with calcium carbonate is relatively non-corrosive to iron.
Corrosive waters are not saturated with calcium carbonate.
Practically no soluble iron will exist in water saturated with calcium carbonate.

A definite relation exists between alkalinity, carbon dioxide content and pH value. This relation is shown in Figure 14.

Inasmuch as alkalinity and carbon dioxide and oxygen content affect the rate of corrosion and at the same time are reflected in the pH value, it is reasonable to expect the correlation between pH value and relative rate of capacity loss indicated in Figure 15.

Small quantities of CO_2 are present in most natural waters. Carbon dioxide readily dissolves in water, forming a weak acid (carbonic acid) which increases the hydrogen-ion concentration. Acidity of water is generally associated with CO_2 or with organic acids. Some of the CO_2 is needed to maintain chemical equilibrium: to hold in solution the bicarbonates of calcium and magnesium which are the ordinary constituents of alkaline waters. The CO_2 in excess of this amount is truly free or aggressive. Hard waters with high bicarbonate alkalinity can contain fairly high amounts of CO_2 without being aggressive. Soft waters are rendered aggressive by relatively small quantities of CO_2.

Water treated with alum contains CO_2 in proportion to the amount of alum added.

Inter-relation between Alkalinity, Carbon Dioxide and pH Value. The inter-relation between alkalinity, carbon dioxide and pH value, other factors being equal, and the importance of these determinations with reference to rate of corrosion have been referred to before.

Figure 14 based on Tillman's formula, as modified by Wagner and Enslow* and prepared by Donaldson, illustrates the interrelation of these three factors.

As will be seen from Figure 14, water with an alkalinity of 10 p.p.m. will have a pH value of 7.3 in the presence of 1 p.p.m. of CO_2; pH 6.3 with 10 p.p.m. of CO_2; and pH 5.6 with 50 p.p.m. of CO_2. Within certain limits, which are fully described by Wagner and Enslow, this chart may be used to find the third factor when the other two factors are known.

Relation Between pH Value and Relative Rate of Capacity Loss. Analysis of the data furnished the Committee, shows a marked correlation between the pH value of the water supply and the relative rate of capacity loss that will occur in a given number of years. This correlation may be attributed to the definite interrelationship between alkalinity, carbon dioxide content, and pH value, previously referred to, together with the fact that carbon dioxide, dissolved oxygen, alkalinity and temperature have important effects upon the rate of corrosion or tuberculation and the consequent loss of capacity. Because of the simplicity of the pH determination and the extensive records of pH values available and because of the marked correlation between pH value and capacity loss, particular reference will be made to this phase of the subject.

The pronounced correlation, which may overshadow other important variables, is illustrated in Figure 15. The curve drawn was developed by plotting the pH value of the various supplies against the per cent. capacity loss in 30 years. The pH values were taken from analyses furnished to the Committee. The per cent. of capacity loss was obtained from the trend curves of the age-coefficient relation for the same supplies. A 30-year period was selected as representing a length of service commonly employed in design and financing.

Figure 15 shows that under average conditions the capacity loss with various values of pH may be approximated as follows:

pH of Supply.	Approximate Capacity Loss in 30 Years Per cent.
8.0	30
7.5	35
7.0	45
6.5	60
6.0	80

* *Jour. Am. Water Works Assn.*, 1922, 9: 373.

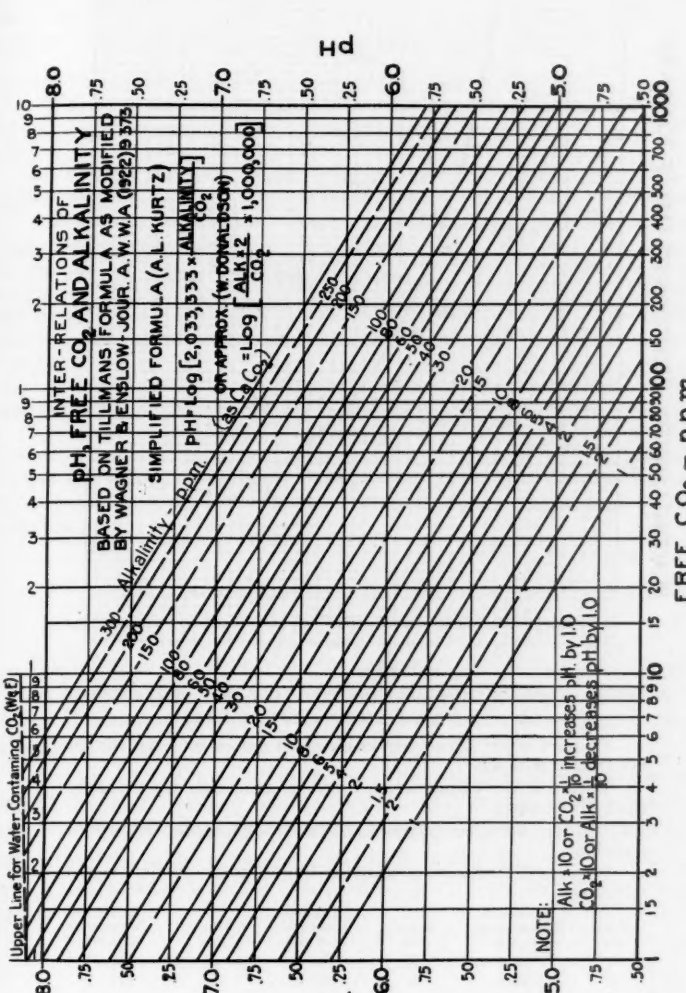
INTER-RELATIONS OF
pH, FREE CO_2 AND ALKALINITY
BASED ON TILLMANS FORMULA AS MODIFIED BY WAGNER & ENGLOW-JOUR. A.W.W.A (1922) 9 375
SIMPLIFIED FORMULA (A.L. KURTZ)
pH = 1.49 [2,033,333 × ALKALINITY / CO_2]
OR APPROX (W. DONALDSON)
(as $CaCO_3$) pH = Log [ALK ÷ 2 / CO_2 × 1,000,000]
Alkalinity - p.p.m.
FREE CO_2 - p.p.m.
pH
Upper Line for Water Containing CO_2 (Wt'd)
NOTE:
Alk. ×10 or CO_2 ÷10 increases pH. by 1.0
CO_2 ×10 or Alk ÷10 decreases pH by 1.0

Fig. 14.

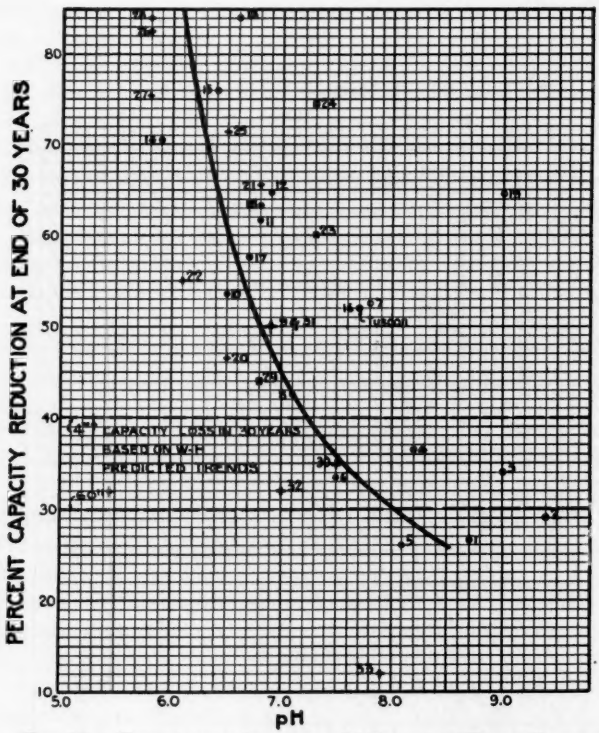

FIG. 15.— CORRELATION BETWEEN pH VALUE OF WATER CARRIED AND 30-YEAR CAPACITY LOSS OF PIPE.

Closed Circles: Trend curves based on numerous tests; supply not treated with lime.

Open Circles: Trend curves based on numerous tests; supply treated with lime.

Crosses: Trend curves based on limited tests; supply not treated with lime.

Squares: Trend curves based on limited tests; supply treated with lime.

Point No.	Reference Designation of Supply.*	Point No.	Reference Designation of Supply.*	Point No.	Reference Designation of Supply.*
1	SM-1	8	SS -1	14	DL -1
2	SM-2	9	SS -2	15	DL -2
3	SM-3				
4	SM-4	10	DS-1	16	DM-1
		11	DS-2	17	DM-2
5	SL -1	12	DS-3	18	DM-4†
6	SL -2	13	DS-4	19‡	
7	SL -3				

* See Figures 4 to 9 for trend curves from which the 30-year capacity loss was derived for each supply. See also descriptive data accompanying these curves for further details of source of supply and water quality.

† DM-3 not available.

‡ No trend curves developed for points 19 to 33.

In an analysis of Figure 15, consideration must be given to the following important factors, which would tend to offset the correlation between pH value and capacity loss. If correlation were not particularly pronounced, it would seem that these variables would obliterate it:

(1) The points refer to mains varying in diameter from 4 to 60 in.

(2) Many of the points pertain to systems in which a change in source of supply and consequent intervening change in rate of capacity loss occurred during the 30-year period.

(3) Some of the points include instances where corrective treatment has been adopted for an unknown and indefinite period, thereby distorting the true relationship.

The most accurate points in Figure 15 are those designated by closed circles. These points represent cases where a well defined trend curve based on numerous tests was available and where no lime was employed in the treatment. Instances in which lime was used in the treatment, with a resulting distortion in the relationship, are shown either by open circles or by open squares. If these points are omitted, the remaining points excluding special cases (Nos. 16 and 33) will be found to fall remarkably close to the curve.

The significance of the various points in Figure 15 is set forth in the caption of Figure 15; the trend curve designations upon which these points are based are also noted.

It is interesting to observe that the capacity loss in 30 years, based on the Williams-Hazen predicted trend, embraces only the portion of the curve between pH 7.2. and 8.0. It is also of interest that only four points fall below the 30 per cent. capacity loss for 30 years predicted in the Williams-Hazen trends; all of the remaining points involve a greater loss for this period of service.

Capacity Loss in Tar-Coated Cast-Iron Pipe Due to Special Causes Other than Tuberculation.

In addition to tuberculation—the most common cause of capacity loss—substantial capacity losses may be developed by other, less common, channel obstructions, such as incrustations, slime or fungus growths and silt deposits.

Capacity Loss Due to Incrustations. Incrustation is perhaps the most frequent cause of capacity loss other than that due to tuberculation. It may be associated either with precipitation from solution of natural mineral matter dissolved in the water, or with precipitation subsequent to chemical changes associated with water treatment. Examples of incrustation of pipe follow.

FIG. 16.—INCRUSTATION OF 6-IN. PIPE DUE TO PRECIPITATION OF NATURAL MINERAL CONTENT OF WATER CARRIED. SANTIAGO, CUBA.

Santiago, Cuba. A typical and interesting example of extensive precipitation of a high natural mineral content of water, resulting in the formation of a thick layer of incrustation on pipe, is illustrated in Figure 16. This pipe was taken from a collecting main in the San Juan well field at Santiago, Cuba, which conveyed water from a series of wells equipped with air lifts to a common suction well at the main pumping station. The internal diameter of the original pipe, 6.15 in., was reduced to 4.12 in. after formation of the deposit. This is stated to have occurred within a period of seven years.

If it is assumed that the original pipe had a value of C = 125, and that the new interior surface was as smooth as that of new pipe,— which was not the case,— the equivalent value of C, after incrustation, would be 44. The loss of capacity in seven years, therefore, is 65 per cent.

FIG. 17.— INCRUSTATION REMOVED FROM 16-IN. CAST-IRON MAIN CARRYING A HIGHLY MINERALIZED WATER. ATHENS, GREECE.
(Courtesy *Compressed Air Magazine.*)

Athens, Greece. An interesting report of the formation of a thick layer of incrustation has recently been made from Athens, Greece. A 16-in. cast-iron main, 7 445 ft. in length was laid in 1918 to convey water from a small supply developed by galleries and Artesian wells at Kokkinar, near Kafissia, a suburb of Athens, to the Hadrian Aqueduct constructed between 115 and 130 A.D.

This water has a hardness of 298 p.p.m. of which 263 p.p.m. are carbonate hardness. In 15 years, a thick layer of hard lime deposit formed in the pipe, causing excessive reduction in capacity. In some sections the deposit reached a depth as great as 5 in. It is believed that incrustation was accelerated by aeration in the line. Steep grades caused the line to flow only partly full the greater part of the time and resulted in cascading and consequent aeration.

The type of material removed from this line is shown in Figure 17. Further reference to this case may be had in an article, "Removing Incrustation in Pipe" by J. R. Shotton.*

* *Compressed Air Magazine*, page 4662, February, 1935.

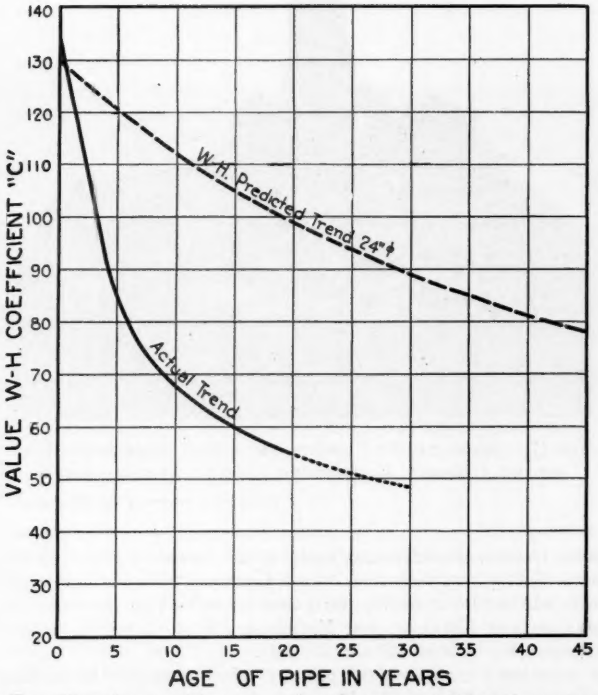

FIG. 18.— ACTUAL TREND OF AGE-COEFFICIENT RELATION FOR TAR-COATED CAST-IRON SUPPLY AND TRANSMISSION MAINS AFFECTED BY INCRUSTATIONS.

The supply is drawn from a river and is softened by the lime-soda process. The curve is based on 23 tests; the weighted average diameter of pipe is 23.2 in; the pH value of the water is approximately 9, and the 30-year capacity loss is 64.5 per cent. The Williams-Hazen predicted loss for a 24-in. pipe is 31.5 per cent.

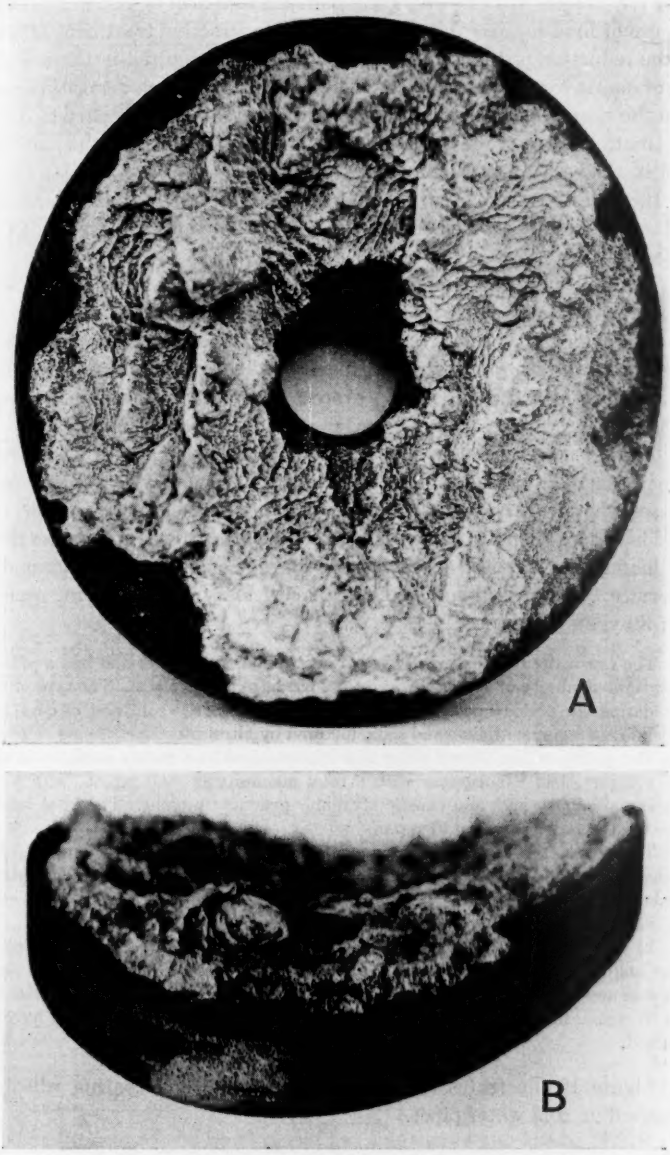

FIG. 19.— INCRUSTATION OF PIPE CARRYING LIME-SOFTENED WATER.
(A) Front View. (B) Side View.

Precipitation of Lime and Incrustation Subsequent to Water Treatment. The use of lime to raise the pH value in the corrective treatment of water for the reduction of tuberculation, has frequently resulted in the incrustating of mains, services and meters. The magnitude of such deposits depends upon the character of the raw water, particularly its adaptability to corrective treatment, upon the extent of corrective treatment and the care exercised in the control of chemical feed.

Incrustations have occurred where lime and ferrous sulphate have been used as coagulants, coincident to the maintenance of relatively high pH values.

The third condition under which water treatment has resulted in incrustation of pipes is associated with the lime process of softening.

Example of Incrustation Caused by the Lime-Soda Process of Water Softening. An example of serious capacity reduction by incrustation following the adoption of the lime-soda process for water softening is illustrated in Figure 18.

Twenty-three tests on pipe lines in this system, with an average diameter of 23.2 in., showed as steep a coefficient trend with age as is found in cases where tuberculation is rapid with an extremely active water. The trend in Figure 18 indicates a value of C = 48 after 30 years, compared with a Williams-Hazen predicted value of 89 for pipe of similar diameter and age of service. Otherwise expressed, a capacity loss of 65 per cent. occurred after 30 years of service.

The raw water for this supply was drawn from an Ohio river and had a pH value of 7.9, total alkalinity of 156 p.p.m. and total hardness of 260 p.p.m. The type of treatment during the period upon which the trend curve is based consisted of coagulation with alum, softening with lime and soda, followed by filtration.

The quality of the filtered water was characterized by a widely varying pH value, usually higher than 9.0 together with a total alkalinity of 52.0 p.p.m., with phenolphthalein alkalinity high and caustic alkalinity generally present. The total hardness of the treated water averaged 97 p.p.m.

The lime-softened water was super-saturated with normal carbonates of calcium and magnesium, and extensive incrustation occurred. Difficulties were not confined to the distribution mains, but trouble was experienced with meters, filter sand and particularly with hot-water pipes.

In recent years recarbonation of the water has been introduced, resulting in a rather uniform pH value averaging 9.0 and a total alkalinity of 35 p.p.m., with phenolphthalein and caustic alkalinity absent. The total hardness, after recarbonation, averaged 86 p.p.m. in recent years, and the difficulties which formerly obtained have been corrected.

Figure 19 illustrates the appearance of the lime coating which was deposited on cold water pipes.

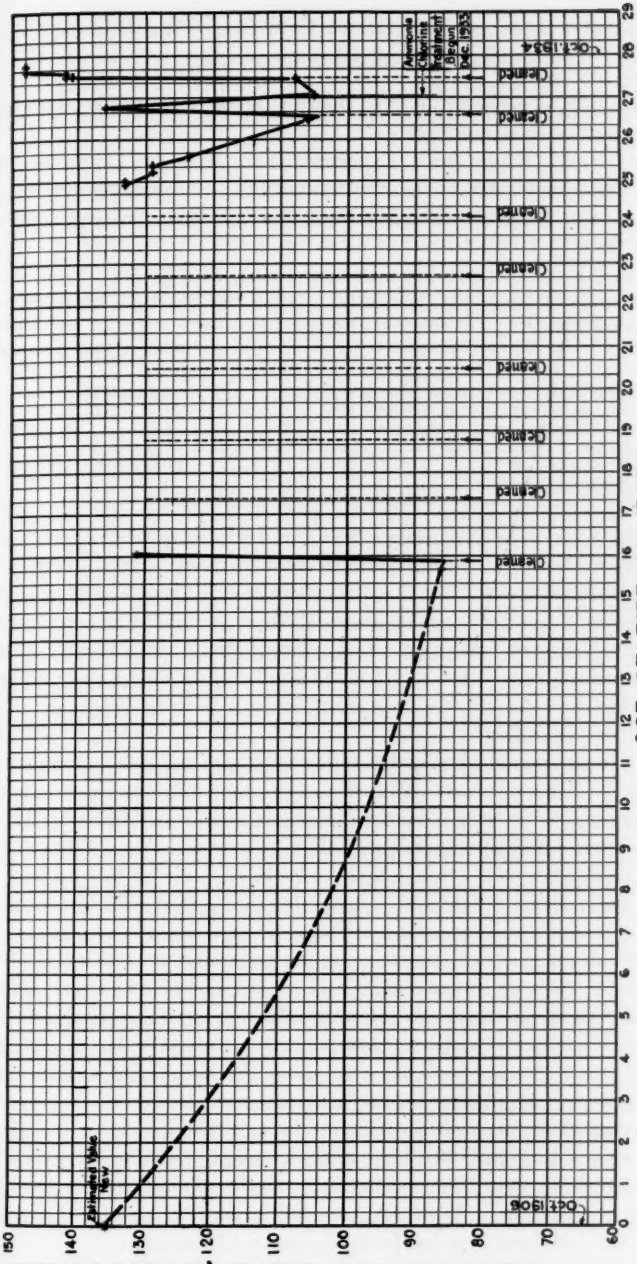

FIG. 20.— EFFECT OF PIPE CLEANING AND AMMONIA-CHLORINE TREATMENT OF WATER ON CARRYING CAPACITY OF 24-IN. SUPPLY MAIN AT UTICA, N. Y.

Capacity Loss in Tar-Coated Cast-Iron Pipe Due to Slime and Fungus Growths.

No instance of capacity loss due solely to slime or fungus growths has been reported to the Committee.

Utica, N. Y. Experience. Experience with a 24-in. supply-line at Utica, N. Y., indicates that part of the difficulty encountered in maintaining capacity in this particular line has been due to a very rapidly forming growth of slime.

This supply-line, 63 800 ft. in length, carries water from Hinckley Reservoir to Marcy's Summit, 12 miles distant. The supply is derived from a heavily wooded watershed 400 sq. miles in area. The area is characterized by igneous and other rock formations which result in an unusually soft water, having the following average characteristics:

Iron at upstream end of pipe line	0.42 p.p.m.
Iron at downstream end of pipe line	0.48 p.p.m.
pH value	6.5
CO_2	23.0 p.p.m.
Hardness	39.0 p.p.m.
Suspended residue	0.52 p.p.m.

During a period of 11½ years it was found necessary to clean the main at intervals averaging 17 months, and in some instances a 20 per cent. loss of capacity occurred within six months after cleaning. The loss of capacity was caused by a quickly forming brown slime as well as by tuberculation.

It was believed that the Reddick-Linderman hypothesis, which ascribes tuberculation to the activities of iron bacteria, might apply to this line and that, accordingly, elimination of the iron bacteria by chlorination might reduce the difficulty.

The line was cleaned, and a sufficient quantity of chlorine and ammonia was applied at the reservoir entrance to the pipe, to maintain a residual chlorine content of 0.2 p.p.m. at the downstream end. At the beginning of the experiment 8.6 lb. of chlorine per million gallons were required to maintain this residual; at the present time, only 40 per cent. of this amount is required, indicating a diminished demand due to changed conditions within the pipe.

Since chlorination equipment, including ammoniators, was installed on December 13, 1933, an unusual change in coefficient value has been noted. For the first time in many years the relatively high capacity obtained after cleaning has seemingly persisted, and present coefficient values are higher than ever before. Recent tests show values of 142 to 148, indicating a very marked change in conditions due to this treatment.

A further description of the Utica case may be found on page 310 of this report, and in Figure 20 which shows a record of coefficient values.

Further data upon this unusual case may be found in an article by George C. Hodges, and J. Walter Ackerman,* upon "Maintaining Carrying Capacity of Cast-Iron Pipe by Introduction of Chloramines."

*Jour. Am. Water Works Assn., Jan., 1935, Vol. 27, No. 1, page 86.

Rochester, N. Y. Experience. An interesting example of marked capacity loss associated with the growth of fresh-water sponge is afforded by experience with a 26-in. cast-iron main at Rochester, N. Y. The erratic changes in the value of C in this line are illustrated in Figure 21.

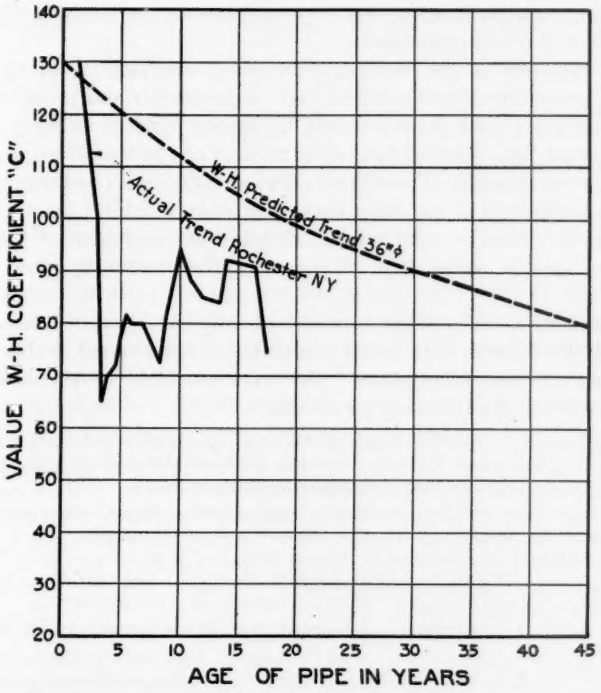

FIG. 21.— ACTUAL TREND OF AGE-COEFFICIENT RELATION FOR TAR-COATED CAST-IRON SUPPLY MAIN AFFECTED BY SPONGE GROWTHS AS WELL AS TUBERCULATION. ROCHESTER, N. Y.

Early inspections of this line revealed the presence of extensive organic growths attached to the top and sides of the pipe, with tuberculation on the lower part. Several growths over 1 sq. ft. in area were found stretching like a curtain across the top of the pipe. By analysis, the growths were found to consist of two species of polyzoa and one of fresh-water sponge.

This Rochester conduit carries untreated Hemlock Lake water. It is 1 000 ft. long.

SECTION III.

COEFFICIENT VALUES OF CEMENT-LINED PIPE.

The cement-lining of water mains dates back at least to 1888. Early methods in use produced comparatively thick linings which did not possess a uniformly smooth interior, free from undulations, particularly when the pipe was over 6 in. in diameter.

Development of the centrifugal process of applying the lining to the pipe, appreciation of water-cement ratio requirements and proper cement curing methods, and improvements in cement quality to meet special requirements, have resulted in a better product and increased use of cement linings for water mains. The centrifugal process makes it possible to employ thinner linings and at the same time to produce a denser, more uniform, and smoother surface, than before. Reduced encroachment of the water way and greater smoothness of cement surface naturally yield higher coefficients.

Information on coefficient values for different types of cement-lined pipe is limited. Such data as are available are summarized in this report.

Summary and Conclusions. The data available to the committee permit drawing the following conclusions:

(1) Except in comparatively rare cases in which sponge growths develop in the pipe, a properly applied cement lining will maintain the hydraulic capacity of the pipe substantially at its initial value for a considerable period of service.

(2) The value of C for centrifugally applied cement linings, based on *actual net diameter*, will vary from C = 145 to C = 150 with best workmanship.

(3) Diameter encroachment by cement linings, at least for pipe 24 in. or less in diameter, is sufficiently significant to warrant expressing the value of C both in terms of *nominal* and *actual net diameter*.

(4) Values of C for different types of cement lining will approximate the following:

Classification.	Williams-Hazen Coefficient C Based on Nominal Diameter.	Williams-Hazen Coefficient C Based on Actual Net Diameter.
Cast-iron Pipe with Centrifugally Applied Cement Lining		
Average of all tests (Table 8)	131*	147
Special Test Lines without bends, specials, or other obstructions to flow	....	149
Cast-iron Pipe with Natural or Rosendale Cement Lining not Centrifugally Applied		
Average of all tests for 6-in. pipe	116	136†
Average of all tests for 16-in. pipe	128	....
Old-style Cement Pipe, Wrought Iron with Cement Lining and Wrapping		
Average of all tests	103	104‡

Detailed Test Data. The results of available tests to determine the values of C for different types of cement lining are summarized in Table 8.

* May vary from 110 to 145 depending on diameter and thickness of lining; maximum age 6 years.
† Average for one 6-in. and one 16-in. line; age from 0 to 10 years. ‡ 41 years old.

Coefficients of Pipe With Centrifugally Applied Cement Lining. Seven series of tests on pipe with centrifugally applied cement lining are available. As will be seen from the following tabulation, the results in each series are quite consistent with the average for all series.

Location.	Length of Test Sections (Feet).	Nominal Diameters (Inches).	Values of Williams-Hazen C Based on Nominal Diameter.	Values of Williams-Hazen C Based on Actual Net Diameter.
West Palm Beach*	700 to 1 500	6 to 24	132	146
Committee No. 1*	555 to 1 190	6 to 8	134	...
Belmont, Mass.*	1 600 to 1 743	6 to 10	121	...
Charleston, S. C.*	250 to 400	6 to 8	136	144
Urbana, Ill.†	192 to 218	4 to 8	133	150
Versailles, Pa.†	1 000	12	133	146
Average			131	146

As might be expected, the two sets of tests performed on lines laid on absolutely straight line and grade for test purposes, showed slightly higher values of C than lines tested in actual service in distribution systems.

Coefficients of Pipe with Natural or Rosendale Cement Lining, not Centrifugally Applied. Information was available for only two lines having a "Natural or Rosendale" cement lining which had not been centrifugally applied. In one case the test was made on the pipe only when new, in the other case a 16-in. line was tested after being in service for 2 months; 1 year and 2 months; 7 years and 7 months; and 10 years and 7 months. Average values of C for these two lines are 126 and 136, for nominal and actual net diameters respectively. When compared with a value of C = 150 for centrifugally applied lining, the value of C = 136 for this type of lining seems to represent a reasonable differential.

Coefficients of Old-Style "Cement Pipe." Information on only one test is available for the "stove pipe" type of cement-lined pipe constructed of wrought sheet-iron, cement-coated inside and out. This test was made on a line 41 years old. The value of C = 104 may well reflect the relative lack of smoothness and uniformity of the interior obtained in early practice, rather than the effect of age.

Series No.	Test No.	Age. Yrs.	Age. Mos.	Williams-Hazen C Based on Nominal Diameter.
C-7	24	0	3	137
	24a	6	0	135
C-8	27	0	2	124
	27a	1	2	120
	27b	7	7	137
	27c	10	7	131

* Mains in service in distribution systems.

† Line erected for test purposes only. Absolutely straight line and grade. No specials or taps.

TABLE 8.— SUMMARY OF AVAILABLE DATA ON TESTS TO DETERMINE ... WITH DIFFERENT TYPES

Location, Date, Authority and Reference.	Class of Pipe.	Specifications for Lining. Description.	Lining Thickness.	Test Data. Pipe Diameter. Nominal.	Pipe Diameter. Actual Net.	Age of Pipe at Time of Test. Yrs.	Age of Pipe at Time of Test. Mos.	Length of Test Section.	Velocity Based on Net Lined Dia.	Head Loss.
			Inches.	Inches.				Feet.	Ft/Sec	Feet per 1000 ft
										Pipe with Centrifugally
West Palm Beach, Fla., 1927 Malcolm Pirnie Unpublished.	Class B A. W. W. A. 12 ft. long, Cement Joints.	1 Part Sand 3 Parts Cement.	3/16	6	5 5/8	0	2	862.3	6.57	19.6
									4.56	10.0
		A. W. W. A. Standard Specifications for Centrifugally Applied Cement Lining.	3/16	6	5 5/8	0	3	1,026.6	6.02	19.0
									4.13	8.95
			3/16	6	5 5/8	0	4	903.3	4.08	6.75
									4.98	14.28
			3/16	6	5 5/8	0	4	903.3	4.34	7.82
									5.70	13.54
			3/16	6	5 5/8	0	4	711.6	5.10	12.95
			3/16	8	7 5/8	0	5	897.0	3.45	5.27
			3/16	8	7 5/8	0	2	1,061.9	5.40	10.55
									3.14	5.27
			1/8	8	7 3/4	1	3	755.5	4.10	8.66
			3/16	12	11 5/8	0	5	840.2	4.38	4.11
			1/8	12	11 3/4	1	2	966.6	3.83	3.59
			3/16	16	15 5/8	0	2	831.0	3.76	2.32
			1/16	16	15 7/8	1	4	1,069.7	3.67	2.38
			1/16	16	15 7/8	1	4	1,069.7	4.30	3.21
									2.58	1.13
			1/8	16	15 3/4	1	5	963.0	4.28	4.94
			3/16	20	19 5/8	0	7	961.0	4.95	4.23
			3/16	24	23 5/8	0	3	1,503.0	3.46	1.31
			Average Coefficient Values[2]							
1933 Frank A. Barbour Unpublished.	No Data.	No Data.	No Data	6	No Data	6	0	555.4	.....	25.00
				6		6	0	555.4	.....	17.70
				8		4	0	1,190.0	.....	7.55
				8		4	0	1,190.0	.....	14.30
				8		4	0	1,190.0	.....	5.40
			Average Coefficient Values							
Belmont, Mass. 1934 Charles W. Sherman Unpublished.	Class 150 DeLavaud.	Substantially in Accordance with A. W. W. A. Standard Specifications.	Est. 1/16 to 3/32	10		6	0	1,600.0	.....	.....
Belmont, Mass. 1933 Charles W. Sherman *Jour. N. E. W. W. A.*, Sept., 1934, Vol. 48, p. 300.	Class 150 DeLavaud 12- and 16-ft. lengths.	Substantially in Accordance with A. W. W. A. Standard Specifications, Spun Lining.	Est. 1/16 to 3/32	8	[2]	5	0	1,743.0	3.18	5.76
			Est. 1/16 to 3/32	6		5	6	1,653.0	Wide Range	
University of Illinois Urbana, Illinois 1927 Melvin L. Enger *Jour. A. W. W. A.*, Oct., 1927, Vol. 48, p. 409. See also Appendix 3 this report	A. W. W. A. Standard 12ft. Lengths, Pit-Cast.	Standard Specifications, Spun Lining.	0.145	4	3.61	New		193.15	Wide Range of Velocity for Each Size	
			0.080	6	5.84	New		218.5		
			0.070	8	7.86	New		192.5		
			Average Coefficient Values							

VALUES OF WILLIAMS-HAZEN COEFFICIENT C FOR CAST-IRON PIPE OF CEMENT LINING.

WILLIAMS-HAZEN COEFFICIENT C. Based on Nominal Dia.	WILLIAMS-HAZEN COEFFICIENT C. Based on Actual Net Dia.	Test No.	Test Methods.
Spun Cement Lining.			
134	160	1	FIELD TESTS. *Head:* By Mercury Manometer connected by ¾-in. Galvanized Iron Pipe to each end of Test Section. *Flow:* By Calibrated Nozzles and Pitot Tube; Velocity Head read on 50-ft. Altitude Gage.
129	153	2	
147	174	3	
144	170	3a	
131[1]	156[1]	4	
123	139	5	
134	152	6	
116	126	7	
145	158	8	
140	148	9	
137	147	10	
142	144	11	
145	148	11a	
109	114	12	
119	125	13	
140	147	14	
132	146	—	
142	No	15	FIELD TESTS. *Head:* By Pressure Drop on calibrated Pressure Gages, with corrections for domestic Flow. *Flow:* By Hydrant Pitots.
122	Data	15a	
147		16	
133		16a	
127		16b	
134			
121	.....	17	FIELD TESTS. *Head:* By Pressure Drop on calibrated Pressure Gages. Without corrections for domestic Flow; 8–10 P.M. *Flow:* By Hydrant Pitot.
122[3]		18	FIELD TESTS. *Head:* By Pressure Gages calibrated before and after Tests. Gage Elevations by leveling. *Flow:* By Pitometer with rough checks by Hydrant Pitot and increase in master Venturi Meter Flow during Test.
120[3]		19	
113[4]	149	20	LABORATORY TESTS. *Pipe Area:* By Average vertical and horizontal diameter of each pipe measured 8 in. from the ends. *Head Loss:* By Differential Gages with Mercury and Carbon Tetrachloride depending on Velocity. *Flow:* By 8-in. by 3½-in. Venturi Meter with Mercury on some Tests and Carbon Tetrachloride on others. Venturi calibrated using each kind of differential Gage.
141[4]	150	21	
144[4]	152	22	
133	150		

TABLE 8.— SUMMARY OF AVAILABLE DATA ON TESTS TO DETERMINE ... WITH DIFFERENT TYPE...

Location, Date, Authority and Reference.	Class of Pipe.	Specifications for Lining.		Test Data.							
				Pipe Diameter.		Age of Pipe at Time of Test.		Length of Test Section.	Velocity Based on Net Lined Dia.	Head Loss.
		Description.	Lining Thickness.	Nominal.	Actual Net.					
			Inches.	Inches.		Yrs.	Mos.	Feet.	Ft Sec	Feet per 1000 ft.
										Pipe with Centrifugally
Versailles, Pa. 1929 J. L. W. Birkinbine *Jour. A. W. W. A.*, Nov., 1931, Vol. 23, p. 1649.	Steel Pipe Matheson Joints Bell and Spigot.	Standard Specifications, Spun Lining.	0.332	12.09	11.426	New		1,000.0	2.56	1.70
									3.50	3.21
									5.01	6.06
									5.63	7.57
									6.87	10.88
									8.20	15.38
									9.24	19.25
				Average Coefficient Values.....						
Charleston, S. C. Aug., 1924; May 1930; May, 1933 James E. Gibson *Jour. N. E. W. W. A.*, Mar. 1926 Acipco Bulletin Unpublished.	A. W. W. A. Standard.	Portland Cement Lined, Centrifugally Placed.	1/16	6	5 7/8	0	3	250	2.5-5.6	3.8-10.3
	A. W. W. A. Standard.	Same Line as above.	1/16	6	5 7/8	6	0	250	2.5-4.5	3.8-11.3
	Sand Spun Cast Iron.	Centrifugal Lining.	5/64	8	7.836	New	0	400	1.4-2.7	.....
				Average Coefficient Values.....						
										Cast Iron Pipe with Thin Natural or Rosendale
Charleston, S. C. Dec., 1922; Dec., 1923; Dec., 1923; May,1930;May,1933 James E. Gibson *Jour. N. E. W. W. A.*, Mar., 1926, p. 107 Acipco Bulletin.	Standard Cast Iron.	Natural or Rosendale Lining (Not Centrifugally Applied).	3/16	6	5 5/8	New	.....	500	1.2-4.5	1.0-12.5
			3/16	16	15 5/8	0	2	500	.9-2.0	.27-.89
			3/16	16	.....	1	2	500	.9-2.4	.21-1.6
			3/16	16	.....	7	7	500	1.7-4.2	.5-3.2
			3/16	16	.....	10	7	500	.....	.....
				Average Coefficient Values.....						
										Old Style "Cement Pipe" Wrought Iron with Cement
Greensburg, Pa. H. E. Beckwith *Water Works and Sewerage*, Vol. 69, Mar., 1930, p. 85.	Old Style Wrought Iron and Cement.	Pipe consisted of Two Layers of Wrought Iron with Cement between and also with Cement Layer on inside and outside. Presumably not Centrifugally Spun as Lines laid in 1888.	See Col. at left.	12	12	41	0	7,854	2.60	3.20
				14	13.81	41	0	12,581	2.54	2.62
				Average Coefficient Values.....						

Remarks.

NOTE: Coefficient Values grouped by brackets involve separate tests on same pipe line.
Letters after test numbers, i.e. 3a designates additional tests of same pipe line.

[1] This line contained two 90-degree Bends with Loss of Head = $12 \frac{v^2}{2g}$.

[2] Average of Tests 3 and 3a and Tests 11 and 11a used to compute final average of this group.
[3] Average Values for 4 Tests.

VALUES OF WILLIAMS-HAZEN COEFFICIENT C FOR CAST-IRON PIPE OF CEMENT LINING, (*Continued*).

WILLIAMS-HAZEN COEFFICIENT C. Based on Nominal Dia.	WILLIAMS-HAZEN COEFFICIENT C. Based on Actual Net Dia.	Test No.	Test Methods.
Spun Cement Lining (*Continued*).			
			LABORATORY TESTS.
129	150	23	
129	148	23a	*Head:* By Manometer Tubes with Mercury connected to both ends of Test Section by ¾-in.
127	148	23b	Galvanized Steel Pipe.
128	148	23c	*Flow:* By Pitometer Co. using bromoform (diluted with Carbon Tetrachloride when necessary)
127	147	23d	in Manometer Tubes.
126	146	23e	
126	146	23f	
127	147		
137	145[5]	24	*Head:* By Mercury Manometer. *Flow:* By Disc Type Meter.
135	142[6]	24a	*Head:* By Acet. Tetrabromide Manometer. *Flow:* By Disc Type Meter.
145	153[7]	25	*Head:* By Acet. Tetrabromide Manometer.
139	147		*Flow:* By 3-in. Trident Crest Meter. Average 5 Tests.
Cement Lining. (Not Centrifugally Applied).			
116	137[8]	26	26 *Head:* By Carbon Tetrachloride and Mercury Manometers. *Flow:* By 4-in. Crest Meter (Pitot Tube also used).
124	132	27	27 to 27c *Head:* By Carbon Tetrachloride and Mercury Manometers.
120	128	27a	*Flow:* By Pitot Tubes.
137	145	27b	
131	140	27c	
126	136		
Inside and Outside. (Not Centrifugally Applied).			
105	105	28	*Head Loss:* By Calibrated Recording Gages.
101	102	29	*Flow:* By Pitometers.
			Remarks: Probably fairly accurate and representative of Values of C for old-style cement pipe.
103	104		

[4] Average Values of numerous Tests.
[5] Average Values for 5 Tests.
[6] Average Values of 6 Tests.
[7] Average Values for 5 Tests.
[8] Average Values of 6 Tests.

Lasting Qualities of Cement Linings. The few available results of tests conducted on cement-lined pipe after substantial periods of service indicate that initial coefficient values may be well maintained. Results for two lines tested both when new and after service periods up to 6 and 10 years, are shown in the tabulation at bottom of page 289.

Inspection of Table 8 indicates that the somewhat lower values recorded for some of the older lines may be due primarily to differences in manufacture rather than effects of age.

Comparison of Coefficient Values Based on Nominal and Actual Net Diameters. The thickness of cement lining ordinarily employed will measureably reduce the values of C due to encroachment of the water way by the lining, particularly in pipe less than 24 in. in diameter.

In four series of tests performed on centrifugally lined pipes, the relative values were as follows:

	Williams-Hazen C.		
	Based on Nominal Diameter.	Based on Actual Net Diameter.	Difference.
	132	146	14
	133	150	17
	127	147	20
	139	147	8
Averages.....	133	148	15

One series of tests (No. 20, 21 and 22) conducted on pipe 4, 6, and 8 in. in diameter under conditions favoring high precision, illustrates the diminishing effect of diameter encroachment on values of C as the pipe size increases. It will be noted that the values based on actual net diameter are remarkably uniform.

Diameter in Inches.		Williams-Hazen C.	
Nominal.	Actual Net.	Based on Nominal Diameter.	Based on Actual Net Diameter.
4	3.61	113	149
6	5.84	141	150
8	7.86	144	152

Reduction in diameter of various sizes of pipe by a 3/16-in. lining necessitates a substantial increase in C to offset this encroachment of the water way if discharge and head loss remain constant. This is shown in the following tabulation:

Original Diameter (Inches).	Net Diameter After Lining (Inches).	Williams-Hazen C.		Required Increase In Value of C.
		Original Pipe.	Necessary Value of C*.	
4	3.625	130	168	+38
6	5.625	130	154	+24
12	11.625	130	141	+11
24	23.625	130	136	+ 6

* To produce same capacity at same head loss as original pipe with C = 130.

SECTION IV.

COEFFICIENTS OF PIPE WITH CENTRIFUGALLY APPLIED BITUMASTIC-ENAMEL LINING.

The centrifugal process of lining cast-iron pipe with bitumastic enamel produces an extremely smooth pipe interior with much higher capacity coefficients for new pipe than those obtainable by other means. There is scant information on coefficients for this type of lining. Such results of tests as are available are brought together in this report. The tests were made on 10, 12 and 20-in. cast-iron pipe, and 30-in. steel pipe lined with bitumastic enamel.

Summary and Conclusions. Analysis of the available data warrants drawing the following conclusions:

(1) Pipe with centrifugally applied bitumastic-enamel lining, when new, will have a capacity approximately 15 per cent. in excess of that of new (unlined) tar-coated cast-iron pipe, based on nominal diameters.

(2) The available information indicates that the coefficients of new pipe of this type will approach the magnitudes shown in the following tabulation.

Classification.	Williams-Hazen Coefficient C Based on Nominal Diameter.	Estimated for New Unlined Tar-Coated Pipe.
Supply and Transmission Mains 16 in. in Diameter and Larger		
Best Conditions — Straight line and grade.....	160	....
Worst Conditions — Many Bends, winding route..	145	....
Average Conditions.....	155	135
Distribution Mains Less Than 16 in. in Diameter		
Best Conditions — Few branches, few services, straight alignment.....	150	....
Worst Conditions — Frequent branches, services and specials.....	140	....
Average Conditions.....	145	125

Discussion of Test Data. The known coefficient values for pipe lined with bitumastic enamel, centrifugally applied, pertain to four series of tests.

Parsippany-Troy Hills, N. J., 10- and 12-in. Cast-iron Pipe. A series of tests conducted at Parsippany-Troy Hills, N. J., was run on *new* 10- and 12-in. cast-iron pipe in a distribution system. The average value of the Williams-Hazen C expressed in terms of both nominal and actual net diameters, was 150.

Weston, Mass., 12-in. Cast-iron Pipe. A series of tests, at Weston, Mass., was conducted on 12-in. cast-iron pipe in a distribution system, *after 1½ years of service.* The average value of the Williams-Hazen C was 158, based on nominal diameter, and 167, based on the actual net diameter of 11.71 in. after lining.

Alhambra, Cal., 20-in. Cast-iron Pipe. A series of tests, was made on a two-mile force main at Alhambra, Cal. This is said to be the first installation of this type on the Pacific Coast. The pipe was Class 100 de Lavaud pipe of 20-in. nominal diameter with a spun lining ⅜-in. thick. The commercial thickness of such pipe is 0.58 in., the

TABLE 9.— SUMMARY OF DATA ON TESTS TO DETERMINE
With Centrifugally Applied

Location, Date, Authority and Reference.	Class of Pipe.	Specifications for Lining.		Test Data.						
				Pipe Diameter.		Age of Pipe at Time of Test.		Length of Test Section.	Velocity Based on Net Lined Dia.	Head Loss.
		Description.	Lining Thickness.	Nominal.	Actual Net.					
			Inches.	Inches.		Yrs.	Mos.	Feet.	Ft/Sec	Feet per 1000 ft
Parsippany Troy-Hills, N. J. April, 1932 Elson T. Killam *Jour. A. W. W. A.*, Vol. 24, Oct., 1932, p. 1590.	Class 150 Warren Spun Pipe 12 ft. long, Leadite Joints	Bitumastic Enamel Centrifugally Applied. Minimum Thickness 3/32 in.	3/32	12	12	0	2	5,271	6.98	10.57
				12	12	0	2	5,490	3.38	0.65
				10	10	0	2	2,857	4.90	
				10	10	0	2	9,406	4.90	6.67
				12	12	0	2	5,490	3.38	0.62
				10	10	0	2	12,263	4.90	
Weston, Mass. April, 1932 Charles W. Sherman *Jour. A. W. W. A.*, Vol. 25, Feb., 1932, p. 244.	Class B Pit-Cast Pipe 12 ft. long	Bitumastic Enamel Centrifugally Applied.	0.145	12	11.71	1	6	2,340	2.29 to 10.40	0.85 to 10.70
Alhambra, Cal. 1933 Thomas B. Downer *Jour. A. W. W. A.*, Vol. 25, May, 1933, p. 630.	Class 100 DeLavaud Pipe.	Bitumastic Enamel Centrifugally Applied.	3/32	20	20.25	2	0	10,600	.....	.....
Lansford, Pa. 1933 Farley Gannett and J. D. Carpenter *Jour. A. W. W. A.*, Vol. 26, Jan., 1934, p. 1.	Steel Welded Longitudinal Joints, 30-ft. lengths, Dresser Couplings.	Bitumastic Enamel Centrifugally Applied. One Foot of each 30-ft. length (at joints) Hand Brushed.	3/32	30	30	0	4	31,900	2.57	.597
									3.15	.88
									3.81	1.251
								18,800	2.57	.580
									3.15	.880
									3.81	1.22
								50,700	2.57	.591
									3.15	.88
									3.81	1.24

VALUES OF WILLIAMS-HAZEN C FOR CAST-IRON AND STEEL PIPE.

Bitumastic Enamel Lining.

WILLIAMS-HAZEN COEFFICIENT C. Based on Nominal Dia.	WILLIAMS-HAZEN COEFFICIENT C. Based on Actual Net Dia.	Test No.	Test Methods.
148	148	1	These Tests on distribution mains in actual Service include losses due to branches, bends, etc.
151.9	151.9	2	Tests No. 1, 2 and 3 involve parts of complete Line consisting of 5 490 ft. of 12-in. and 12 263 ft. of 10 in. pipe reported in Test No. 4.
149.3	149.3	3	*Flow* by hook gage measurements of displacement in 60-ft. diameter Concrete Reservoir.
150	150	4	*Head* by calibrated Pressure Gages working with Total Losses of from 34 to 96 ft. of water. *Flow Checks* by Hydrant Pitot. Bench Levels run and checked between gaging stations. Distances taped. Results for Test No. 1 based on average of readings every ten minutes for 1 hour, 46 minutes. Results for Test No. 2, 3 and 4 based on average of readings every ten minutes for 1 hour, 52 minutes.
158	167	5	These Tests on distribution mains in actual Service include losses due to branches, bends, etc. *Flow* by hydrant Pitot Tubes. *Head* by calibrated Pressure Gages on Total Losses of from 2 to 39 ft. *Bench Levels* run and checked between gaging stations. Results represents average of 12 selected observations or tests on this line.
158	.....	6	Supply Line in Service.
144.3	144.3	7	These Tests on Supply Line with losses introduced by extremely tortuous route involving 66 vertical and horizontal bends, 51 air valves and 51 B. O. connections.
143.2	143.2	8	
143.5	143.5	9	*Flow* by 30-in by 12-in. Venturi Meter.
147.3	147.3	10	*Head Loss* by calibrated Pressure Gages on Total Losses of from 2 to 40 ft.
143.5	143.5	11	Results represent average of observations at 1-min. intervals over test period of 3 hrs. 15 min. for series of 5 Tests at various rates of flow.
145.6	145.6	12	
145.8	145.8	13	Pipe 30$\frac{3}{16}$ in. before lining, 30 in. net after lining.
143.5	143.5	14	Tests No. 7 and 10 involve the complete line reported in Test No. 13, etc.
144.3	144.3	15	

AVERAGE VALUES OF C.

Test No.	Nominal Diameter.	Actual Diameter.
1– 4	149.8	149.8
7–15	144.5	144.5

outside diameter 21.6 in. Accordingly, the net diameter was estimated at 20.44 in. before and 20.25 in. after lining. The value of C *after two years* was 158 based on nominal diameter.

Lansford, Pa., 30-in. Steel Pipe. A series of tests was conducted at Lansford, Pa., on a 30-in. steel line, after four months of service. The pipe was laid in 30-ft. lengths with one welded longitudinal seam. Every third or fourth joint was made by using Dresser couplings; the intermediate joints were welded electrically. The entire line followed an unusually tortuous route. The average coefficient value, based both on nominal and actual net diameter, was 145.

Detailed Test Data. These tests are summarized in Table 9. Nominal and actual diameters, length of test section, range in velocity, head losses upon which computations are based, and coefficient values are included in this table. Test methods and other pertinent data are also described.

Lasting Qualities of Bitumastic-Enamel Linings. The first line with bitumastic-enamel lining applied by the centrifugal method was laid in 1931. There is, therefore, no record of coefficient values after the lapse of a substantial period of time. The longest period of service for the tests herein described was 2 years at Alhambra, Cal. An indication of the expected behavior of this type of lining may perhaps be drawn from the experience with bitumastic-enamel linings applied by the hand-brushed method. Enamel so applied has been widely used for many years. Visual inspection of a number of large-diameter steel lines, hand-brushed with enamel and carrying active water, has shown no deterioration apparent to the eye within a service period of 16 years.

It is to be hoped that numerous tests will be made on new and aging lines to obtain definite records of the age-coefficient relation for this type of lining.

Comparison of Coefficient Values Based on Nominal and on Actual Net Diameters. The thickness of this type of lining ordinarily specified is $\frac{3}{32}$ in. Accordingly, the encroachment on the water way is small as compared with cement, Talbot, and other linings.

The effect of diameter reduction due to any lining is, of course, more pronounced in small mains than in large ones. Taking a 6-in. pipe as illustrating the greatest effect of encroachment, it is found that decreasing the diameter to 5.81 in. by a lining $\frac{3}{32}$ in. in thickness requires an increase of 12 points in the value of C to maintain the same capacity with the same head loss. For a 12-in. pipe, the increase required is 5 points, and for a 16-in. pipe only 3 points.

It appears therefore that the effect of thickness of lining on capacity is not significant in comparison with the substantial losses of capacity ordinarily observed in tar-coated cast-iron pipe.

SECTION V.

COEFFICIENTS FOR MISCELLANEOUS TYPES OF LINING.

Talbot Lining. Talbot lining, introduced in this country in 1925, consists of selected bitumen mixed intimately with a finely-ground inert filler. The bitumen affords protection and the filler widens the temperature range to which the lining can be subjected without cracking or softening. The only coefficient tests, brought to the attention of the Committee, for pipe so lined, are those at Versailles, Pa. discussed in Appendix 3 of this report. These tests were conducted with a high degree of precision on a line 1 000 ft. long, having no bends or other obstructions to flow. Values of $C = 157$, based on actual net diameter, and $C = 133$, based on the inside diameter before lining, were observed. The pipe used was steel pipe 12.09 in. in inside diameter with Matheson bell-and-spigot joints. The lining thickness was 0.332 in.

For further details relative to Talbot linings see Appendix 3 and the following references:

"Corrosion of Water Mains," by H. R. Reddington, J. L. W. Birkinbine and F. N. Speller.*

"Linings and Covering for Water Pipes," by Benjamin Talbot.†

Other Types of Lining. Several other types of lining have been investigated by pipe manufacturers and others. Among the linings that have never reached the quantity-production stage in this country are the following:

Pitch base
Asphalt (with inert filler)
Vitreous enamel

A discussion of these three types may be found in the paper "Linings for Cast-iron Pipe," by D. B. Stokes and H. G. Reddick.‡

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* *Jour. Am. Water Works Assn.*, Vol. 23, Nov. 1931, p. 1685.
† This JOURNAL, Vol. 40, Dec. 1926, p. 446.
‡ *Jour. Am. Water Works Assn.*, Vol. 24, Oct. 1932, p. 1582–1589.

SECTION VI.

LINING SMALL MAINS IN PLACE WITH CEMENT.

Four methods of reconditioning mains by cleaning and lining-in-place have been referred to in the summary of this report. The only one of these four methods for which adequate information is available in the literature is the "Tate" process for providing small-diameter mains in place with cement lining. Since new principles are involved, it seems justifiable to summarize in this report the paper in which the Tate process is described.

Observations on the Tate Process of Reconditioning Corroded Water Mains "In Situ."

By A. Carrington Wildsmith.*†

This paper describes the work performed in a contract awarded to Tate Pipe Lining Processes, Ltd., for reconditioning approximately ten miles of distribution mains 3, 4, and 5 in. in diameter.

In carrying out the work, all services and branches were disconnected, each main was thoroughly cleaned, a quantity of cement mortar placed in it and a plunger, having a diameter slightly less than the interior of the pipe, pulled through, thereby forcing the mortar against the pipe wall in the form of a smooth lining. Formation of a lining, by this method, developed a pressure of 130 lb. per sq. in., resulting in an exceedingly dense lining. The cost of the entire operation was estimated approximately at 40 per cent. of the cost of complete renewal of the mains. One of the principal items of cost was the temporary disconnection of lateral mains, hydrant branches and all corporation cocks. Accordingly, the relative number of services per 100 ft. was an important factor in the cost of relining.

The average Williams-Hazen coefficient for four lines tested was 37 before and 86 after lining, both values being based on nominal diameter. The coefficient based on actual net diameter after lining was 141.

Corporation Cocks Dug Up and Temporarily Removed. Services were first located, generally with the aid of an electric pipe finder. The connections with the mains were excavated, and the corporation cocks removed and replaced with short iron plugs. Great care was taken to verify positions of the corporation cocks, as it was found of utmost importance that every service be identified before scraping began. Corporation cocks left in place might have damaged the cutters of the scraper, or, if not discovered before the main was lined, services would have been filled with mortar which cannot be blown out. In one instance in which a corporation cock was missed, the mortar was forced through a stop cock and through 54 ft. of ¾- and ½-in. lead pipe before being arrested at a bibb tap at the end of the pipe.

Cleaning the Main. A short section of pipe was cut out for insertion of the scraping equipment, and the entire line was then scraped with a gasoline-driven rotary scraper until all tuberculation had been removed. The main was then thoroughly flushed.

Preparations for Lining. Upon the completion of the cleaning operation, a short length of pipe was removed at the other end of the section to be lined. These sections were generally from 200 to 500 ft. long, depending upon the pipe diameter. It was found feasible to line much longer lengths of 4- and 5-in. pipe in one pull than 3-in. pipe, due to a freer flow of the concrete in the larger-diameter pipe.

All lateral branches and hydrant tees were temporarily disconnected and plugged, and valves were cut out and replaced with straight pipe and temporary couplings. Prior

* *Water and Water Engineering*, Feb. 1935, p. 53.

† Engineering Assistant, Manchester Corporation Waterworks.

to lining, a device consisting of a hardened steel cylinder ¼ to ⅛ in. smaller than the nominal pipe diameter, with over-sized rubber plungers mounted both ahead and behind the cylinder, was drawn through the pipe. The purpose of the cylinder was to determine the maximum diameter of lining plunger that can be used and to ascertain the presence and location of any obstructions. The rubber plungers acted as squeegees and removed silt and moisture, leaving the pipe practically dry.

Cement Mortar for Lining. After the pipe had been cleaned and checked for size, cement mortar, consisting of one part cement and two parts washed sand, with a slump of 9 in. was thoroughly mixed for 25 to 60 minutes, depending upon the type of cement used. This mortar was then deposited in the main through a funnel.

Three types of cement were employed: Portland cement, Ferrocrete, and Ciment Fondu. *Portland cement* was used on 8½ of the 12¼ miles of lining undertaken. With this cement, a mixing period of 60 minutes was required. In cold weather a period of 18 hours was necessary to insure proper setting before restoring service in the main. *Ferrocrete mortar* required a mixing period of only 20 minutes and was found to set more rapidly, making it possible to return the main to service 12 to 14 hours after lining. One mile was lined with *Ciment Fondu* mortar. It was found that this type of mortar would set in as little as four hours.

Upon the conclusion of the work it was decided that Ciment Fondu mortar was most suitable, because of its resistance to corrosion, its rapid hardening qualities and its comparatively slight effect on increasing hardness and pH of the supply after lining and because of the shorter mixing period required. The comparatively minor deterioration of water quality by Ciment Fondu, made it possible to use a much smaller quantity of water for flushing the mains than was the case when other types of mortar were employed.

Forming the Lining. After inserting the mortar, the plunger was pulled through the main, forming a lining between the plunger and the pipe wall and crowding the excess mortar ahead. The excess water was forced through perforations in the plunger, leaving a semi-dry mortar adhering to the wall of the pipe. The excess water carried with it a certain amount of sand and cement which collected and set on the bottom of the pipe in the form of a "flat." In some instances, a follower was drawn behind the plunger, distributing the excess material uniformly around the entire circumference. The entire operation of reconditioning a section 450 ft. long could be completed in 24 hours. To minimize inconvenience, a temporary supply pipe was often laid on top of the ground.

Relative Quantities of Excavation and Paving for Relining as Compared with Quantities for Renewal of Mains. In a typical street 830 ft. in length with the main at a depth of 2 ft. 10 in. to the invert, the following quantities of excavation and paving were observed or estimated to be required:

	Actual Quantities for Scraping and Lining.	Estimated Quantities for Renewal of Main.
Paving	62 sq. yd.	287.5 sq. yd.
Excavation	61.5 cu. yd.	239.8 cu. yd.

Three hydrants, three branches and 13 service connections were included in this section, requiring the excavation of 19 connections, or one connection in 44 ft.

Increase in Capacity Obtained by Cleaning and Lining. The coefficient increase obtained by cleaning and lining is illustrated in the following tabulation:

Nominal Diameter of Main (Inches).	Values of Williams-Hazen C.			Increase in C Based on Nominal Diameter Per cent.
	Based on Nominal Diameter		Based on Actual Net Diameter After Lining.	
	Before Lining.	After Lining.		
3	20	65	140	225
4	40	86	140	115
5*	65	98	150	50
5	24	96	135	300

* This main was hand-scraped in 1926 and was lined mainly to stop the bleeding of the rusted metal.

Effect of Lining on Quality of Water. It was found that the lining affected the quality of water for some time after restoration of service, and some complaints were received from consumers. There were reported: difficulty in bathing, "spoiling of the morning tea," and, in two cases, increased pH resulting in the "untimely end of aquarium livestock."

The effect of various types of mortar upon water quality is indicated by the following tabulation:

	Methyl Orange Alkalinity—p.p.m.			Hydrogen-ion Concentration—pH Value.		
Day After Charging.	Portland Cement.	Ferro-Crete.	Ciment Fondu.	Portland Cement.	Ferro-Crete.	Ciment Fondu.
1	470	430	40	11.25	11.50	9.00
2	360	511	20	11.25	11.50	7.50
3	285	276	21	11.25	10.25	7.50
5	170	130	..	11.00	8.00	....
7	110	30	..	10.00	7.50	....
10	32	30	..	9.70	7.50	....
14	20	30	..	9.50	7.50	....
17	20	28	..	9.40	7.50	....
Average of six samples of Manchester water		24			6.50	

A substantial increase in hardness of the water occurred during the week after placing in service Portland-Cement- and Ferrocrete-lined mains. The increase was almost entirely in the form of temporary hardness. The Ciment Fondu mortar had relatively little effect on either the hardness or the pH value.

SECTION VII.

CORRECTIVE WATER TREATMENT FOR REDUCTION OF CORROSION.

The question of corrective treatment to reduce corrosion is only indirectly concerned with pipe-line friction coefficients and is pertinent only because it represents one of the alternate remedial methods for offsetting capacity loss. Brief reference will be made to some of its more important aspects.

General Comments. The addition to water of an alkali to reduce corrosion may be traced back to 1915 and possibly farther back. The first large scale application appears to have been at Baltimore in 1920. In recent years many supplies have included corrective treatment as a normal part of plant operation. Successful corrective treatment requires the following:

(1) Determination of the equilibrium point for calcium carbonate saturation.

(2) Production of slight supersaturation to deposit a thin film of calcium carbonate on the pipe interior.

(3) Determination of the proper point of application of the alkali, depending on the coagulant used and other factors in the treatment process.

(4) Provision of adequate mixing devices effectively to utilize the alkali and collect the residue.

(5) Continuous control of plant within certain limits, at or very near the saturation point. If treatment falls below this point, the coating will be dissolved; if carried above, a deposit of objectionable thickness may be formed.

(6) Determination of the best alkali for use in each case, with respect to cost, effectiveness, and influence on quality of water treated.

Saturation Equilibrium Point of Calcium Carbonate. The saturation equilibrium point of calcium carbonate is subject to considerable variation, depending upon the normal calcium carbonate content or alkalinity of the water, and upon its magnesium content. The pH value at which saturation equilibrium of calcium carbonate is reached in water containing only calcium alkalinity is shown in the following tabulation.* This relation is also shown diagrammatically by Baylis.†

Alkalinity, p.p.m.	pH Value.	Alkalinity, p.p.m.	pH Value.
15	9.3	70	7.8
20	8.9	100	7.6
25	8.7	120	7.5
30	8.5	140	7.4
40	8.1	190	7.2
50	8.0		

* *Jour. Am. Water Works Assn.*, Vol. 19, Apr., 1928, p. 371.
† *Jour. Am. Water Works Assn.*, Vol. 27, Feb., 1935, p. 225.

The pH value at which equilibrium is established is raised in proportion to the part played by sodium or magnesium carbonates in the total alkalinity of a given water. Hence it is not possible to make a general statement as to the pH value that should be maintained by corrective treatment. Requirements are fixed by the quality of the particular water under consideration, with especial regard to its *calcium bicarbonate* content and not to its total alkalinity or total hardness.

As a general rule a pH value of 8.1 is sufficient to stop corrosion in cold water having an alkalinity of 50 p.p.m. or more. If the alkalinity is less, the pH value must be raised; thus for 15 p.p.m. of alkalinity, the pH value must be nearly 9.0. The dividing line between significant absence or presence of free carbon dioxide is at or near pH 8.1.

Difficulties Encountered in Corrective Treatment. Determination of the equilibrium point and pH value of water are readily made, and the mechanics of chemical feed are simple. Maintenance of the proper equilibrium throughout the distribution system is more difficult. This is particularly true of extensive distribution systems in which the changes that occur in the water alter the optimum conditions created at or near the plant to such an extent that under-saturation may occur in remote sections, particularly in dead-ends and sections with sluggish circulation. If, in order to obtain a residual at remote points, the water is super-saturated at the plant, deposits will form in pipes near the point of treatment, and an increase in capacity loss may result.

Chemicals Used for Corrective Treatment. Among the chemicals more commonly used are lime, sodium hydroxide and soda ash. Lime is by far the cheapest of these three. Its use is essential when the alkalinity of the water to be treated is less than 25 p.p.m. In more alkaline waters, sodium alkalies may be used.

Each part per million of CO_2 converted to calcium bicarbonate by lime increases the hardness by 1.136 p.p.m. Sodium hydroxide and soda ash do not raise the hardness.

Hudson and Buswell* estimate that an increase of one part per million of hardness causes an expenditure for soap, boiler treatment, etc. of approximately one cent per capita per year. In selecting the most advantageous and economical chemical for any particular case, its cost as well as its effect on hardness should be taken into consideration.

One of the most complete papers on corrective treatment is "Treatment of Water to Prevent Corrosion, by John R. Baylis.*

The following tabulation is taken from this article. It presents in condensed form a comparison of various chemicals that may be employed for corrective treatment.

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* *Jour. Am. Water Works Assn.*, Vol. 24, June, 1932, p. 859.
* *Jour. Am. Water Works Assn.*, Vol. 27, Feb., 1935, p. 220.

Corrective Chemical.	Cost of Converting CO_2 to Bicarbonate.				
	Commercial Material to Combine with 1 p.p.m. of CO_2.	Cost per Lb. of Commercial Material.	Cost per Million Gal. of Converting 1 p.p.m. of CO_2 to Bicarbonate.	Hardness Increase to Neutralise 1 p.p.m. of CO_2.	Total Cost† per Million Gal. to Reduce 1 p.p.m. of CO_2 to Bicarbonate.
	p.p.m.	Dollars.	Dollars.	p.p.m.	Dollars.
Lime	0.75*	0.005	0.032	1.138	0.242
Sodium hydroxide	0.910	0.025	0.189	0.000	0.189
Soda Ash	2.411	0.012	0.241	0.000	0.241

* Based upon 85 per cent. water soluble CaO.
† Based upon a per capita cost of 1 cent per person per year for each p.p.m. of hardness, and upon an average water consumption of 150 gal. per capita daily.

References.

(1) Factors other than dissolved oxygen influencing the corrosion of iron pipes. *Indust. & Eng. Chem.*, 18: 370–380, Apr., 1926.

(2) Prevention of corrosion and "red water." *Jour. Am. Water Works Assn.*, 15: 598–633, June, 1926.

(3) Mixing baffles cut down chemicals at Jackson, Miss. Baylis, John R. *Eng. News-Rec.*, 80: 364–365, Feb. 21, 1918.

(4) The solution of corrosion and coagulation problems at Montebello Filters, Baltimore. Baylis, John, R. *Jour. Am. Water Works Assn.*, 9: 408–417, May, 1922.

(5) Economics of corrective treatment for cold-water corrosion. Hopkins, E. S., Armstrong, J. W., and Baylis, John, R. *Ind. and Eng. Chem.*, 26: 250–254, March, 1934.

(6) Soap consumption and water quality. Hudson, H. W., and Buswell, A. M. *Jour. Am. Water Works Assn.*, 24: 859–866, June, 1932.

(7) Corrosion following water-purification processes. C. A. Smith. *Jour. Am. Water Works Assn.*, 25: 818, June, 1933.

(8) Red-water trouble and the remedy at West Palm Beach, Fla. L. O. Williams. *Jour. Am. Water Works Assn.*, 22: 791, June, 1930.

(9) A symposium on pipe corrosion and corrective measures. *Jour. Am. Water Works Assn.*, 23: 1540, Oct., 1931.

(10) Treatment of filtered water at Harrisburg. Gould, R. H. *Jour. Am. Water Works Assn.*, 19: 358, Apr., 1928.

SECTION VIII.

RESTORATION OF CAPACITY OF UNLINED CAST-IRON MAINS BY CLEANING.

Recourse is often taken to pipe cleaning in order to remove tuberculation or other causes of capacity loss in cast-iron pipes. Brief reference to this subject will, therefore, be made in this report.

The two most important considerations in cleaning water mains, are:

(1) The immediate increase in coefficient value and capacity obtainable by cleaning.

(2) The rate of capacity loss subsequent to cleaning; in other words, the persistence of the improvement.

Conclusions. Analysis of the data available to the Committee has lead to the following conclusions:

(1) Cleaning will ordinarily restore the main to approximately 85 per cent. of its original capacity.

(2) The effectiveness of restoring capacity depends primarily upon the original cause of capacity loss, *i.e.*, whether it was due to tuberculation, incrustation, mud or slime. Tests indicate that restoration is more effective in tuberculated mains than mains choked by incrustation or lime deposits.

The degree of restoration depends also upon the thoroughness with which cleaning is performed and the extent to which tuberculation has been allowed to progress. There are indications that mains with unusually low coefficients before cleaning, say C equals 20 to 30, are never restored to as high a capacity as mains that are in better condition.

(3) The relatively high capacity observed immediately after cleaning, may be lost rapidly, particularly in the case of small mains. Rate of capacity loss depends on the cause of loss and the relative activity of the water. The rate will ordinarily be quite steep in comparison with the original trend.

(4) Cleaning is an important preliminary step to more permanent methods of restoring and maintaining capacity. Among these methods are: the introduction of corrective treatment and the lining of mains in place.

Capacity Increase Obtained by Cleaning. The increase in capacity normally obtained by cleaning cast-iron mains is indicated in Table 10, which summarizes the results of 35 tests on mains 4 to 30 in. in diameter. It should be pointed out that this table records the results of cleaning operations carried on a number of years ago. It is probable that improvements in methods and equipment may yield more effective results today.

Group 1. The first group of six tests in Table 10 includes mains 4 to 8 in. in diameter carrying a soft and active Long Island well water. The loss of capacity was, accordingly, due strictly to corrosion and subsequent tuberculation. Eliminating the first test which is not in accord with the other five tests, the average value of the Williams-Hazen coefficient was 34 before cleaning and 113 after cleaning. Assuming a C of 125 for the original coefficient, the capacities before and after cleaning were respectively 27 and 90 per cent. of the original value.

Group 2. The second group of six tests shows the effect of cleaning 6- and 8-in. mains in St. Louis. Here the loss of capacity was due to a combination of factors, including silting, tuberculation and incrustation. The mean value of the Williams-Hazen coefficient after an average service of 49 years was 37 before and 86 after cleaning. Referred to an original C of 125, the capacities before and after cleaning were respectively 30 and 69 per cent. of the original value.

Group 3. The third group of tests covers results obtained on 13 mains 4 to 16 in. in diameter, located in 10 different cities. Values of C before cleaning vary from 20 to 78, averaging 41. After cleaning they range from 70 to 130, averaging 103. The average capacity of the group, expressed in percentage of estimated original capacity, was 32 per cent. before and 82 per cent. after cleaning.

Group 4. The fourth group includes 10 tests. Several of them are expressed in terms of the C in Chezy's formula. The information available is insufficient to translate the results into the Williams-Hazen C.

The average results for the first three groups of tests (No. 2 to 25) are as follows:

Total number of mains cleaned	24
Average Diameter — Inches	6.7
Williams-Hazen C	
Before cleaning	39
After cleaning	104
Percentage of original capacity	
Before Cleaning	31
After Cleaning	83

Loss of Capacity Subsequent to Cleaning. Very little information has been furnished the Committee on specific numerical results obtained by cleaning and followed by tests to determine the subsequent loss of capacity. The available data are summarized in this report.

The original cause of capacity loss is an important factor in rate of loss subsequent to cleaning. The data are discussed with reference to this fact.

Active Eastern Surface Waters. The following quotation from an article by J. E. Gibson* describes conditions following cleaning of cast-iron mains at Charleston, S. C., and is indicative of what may happen in supplies carrying extremely active water:

"Experience in Charleston, S. C., has been that the loss in the carrying capacity of standard lined (*i.e.* tar-coated) cast-iron pipe, is approximately 20 per cent. within three years, and that the results of cleaning do not last more than 4 or 5 months, at best."

The 24-in. main supply line from the Hanahan Pumping Station to the city of Charleston was laid in 1903. The line was cleaned in 1914, 1916 and 1919. Before cleaning in 1919 the value of Chezy's C was 72 and immediately after cleaning, 106. In thirty days the value fell to 90.

English Experience. While no numerical results have been found, a general description of English experience taken from an article in *Water and Water Engineering*† is of interest:

"Scraping by hand or by power scrapers has proved to be only a temporary palliative. The main so treated soon becomes corroded or tuberculated again, and this scraping must be carried out at regular intervals if any measure of improvement is to be maintained."

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* *Eng. News-Rec.*, Sept. 7, 1922, p. 388. † Feb., 1935, p. 53.

TABLE 10.— RESTORATION OF CAPACITY OF UNLINED CAST-IRON PIPE BY CLEANING.

Test No.	Location.	Source of Supply.	Reported Cause* of Capacity Loss.	Age When Cleaned (Years).	Pipe Diameter (Inches).	Williams-Hazen C.		Assumed Original Value of C.	Per cent. of Original Capacity.	
						Before Cleaning.	After Cleaning.		Before Cleaning.	After Cleaning.
			Group 1 — Long Island Well Waters.							
1	Long Island	Wells	T	20	8	83	130	130	64	100
2	Long Island	Wells	T	43	6	34	110	125	28	88
3	Long Island	Wells	T	43	6	42	113	125	34	90
4	Long Island	Wells	T	24	4	42	116	125	34	93
5	Long Island	Wells	T	30	6	22	118	125	18	94
6	Long Island	Wells	T	30	4	31	110	125	25	88
	Average of Tests 2 to 6			34	5.2	34	113	125	27	90
			Group 2 — St. Louis, Missouri.							
7	St. Louis, Mo.	Mississippi River	M T & I	48	6	28	93	125	22	75
8	St. Louis, Mo.	Mississippi River	M T & I	59	6	32	86	125	26	69
9	St. Louis, Mo.	Mississippi River	M T & I	47	6	35	88	125	28	70
10	St. Louis, Mo.	Mississippi River	M T & I	49	6	32	81	125	26	65
11	St. Louis, Mo.	Mississippi River	M T & I	44	8	44	85	125	35	68
12	St. Louis, Mo.	Mississippi River	M T & I	45	6	48	84	125	38	67
	Average of Tests 7 to 12			49	6.3	37	86	125	30	69
			Group 3 — Miscellaneous Supplies.							
13	Tarrytown, N. Y.	Surface Water	T	..	16	59	115	135	44	85
14	Philadelphia, Pa.	Schuykill River	M & T	..	6	36	119	125	29	95
15	Brooklyn, N. Y.	Wells	T	..	6	23	78	125	18	62
16	Brooklyn, N. Y.	Wells	T	..	8	20	70	125	16	56
17	Brooklyn, N. Y.	Wells	T	..	12	22	82	125	18	66
18	Perth-Amboy, N. J.	Wells	M & T	..	4	60	125	125	48	100

15	Brooklyn, N. Y.	Wells	T	..	6	23	78	125	18	62
16	Brooklyn, N. Y.	Wells	T	..	8	20	70	125	16	56
17	Brooklyn, N. Y.	Wells	T	..	12	22	82	125	18	66
18	Perth-Amboy, N. J.	Wells	M & T	..	4	60	125	125	48	100
19	Perth Amboy, N. J.	Wells	M & T	..	6	78	120	125	62	96
20	Belle Plaine, Ia.	Small Creek	I	..	6	44	130	130	34	100
21	Troy, N. Y.	Surface Water	T	..	6	51	117	125	41	94
22	Madison, Ind.	Ohio River	M & T	..	4	29	90	125	23	72
23	Little Rock, Ark.	Arkansas River	T	..	6	33	115	125	26	92
24	Rochester, N. Y.	Genessee River	T	..	10	48	96	125	38	77
25	Boston, Mass.	Surface water	T	38	6	35	89	125	28	71
	Average of Tests 13 to 25			..	7.4	41	103	126	32	82
	Average of Tests 2 to 25			..	6.7	39	104	125	31	83

Group 4 — Miscellaneous Supplies (Data incomplete).

26	Utica, N. Y.	West Canada Creek	S & T	16	24	86-a	131-b	...	...	...
27	Utica, N. Y.	West Canada Creek	S & T	16	24	106-c	136-d	...	...	...
28	Utica, N. Y.	West Canada Creek	S & T	16	24	108-e	141-f	...	...	...
29	Brooklyn, N. Y.	Wells	T	..	30	48	135	...	...	...
30	Charleston, S. C.	Goose Creek	T	31	6	34†	90†	...	...	...
31	Mt. Vernon, N. Y.		T	25	4	25†	107†	...	...	...
32	Mt. Vernon, N. Y.		T	..	6	29†	125†	...	...	...
33	Tarrytown, N. Y.	Surface Water	T	..	8	63†	104†	...	...	...
34	Hartford, Conn.	Surface Water	T	37	20	69†	111†	...	...	...
35	Brooklyn, N. Y.	Wells	T	..	..	48	120	...	...	...

* T — Tuberculation. I — Incrustation. M — Mud Deposits. S — Slime. † These values are expressed in terms of the Chezy C.
a — Value 97 days before cleaning.
b — Value 34 days after cleaning.
c — Value 52 days before cleaning.
d — Value 32 days after cleaning.
e — Value 6 days before cleaning.
f — Value 4 days after cleaning.

References: Tests 7–12 — *Jour. Am. Water Works Assn.*, 1929, p. 733.
Tests 13, 33 — *Jour. Am. Water Works Assn.*, Vol. 22.
Tests 14–24, 29, 35 — *Jour. Am. Water Works Assn.*, 1911, p. 40.
Test 25 — This JOURNAL, 1898, p. 343.
Tests 30–32 — *Eng. News-Rec.*, Sept. 7, 1922.
Test 34 — *Eng. News*, Nov. 1913, p. 1099.

Utica, N. Y. Interesting information on cleaning and subsequent loss of capacity is available for a 24-in. supply main some 63 800 ft. in length. This main has been frequently cleaned, and a substantial number of tests has been conducted before and after cleaning. During a period of 11½ years, this main was cleaned 8 times, or approximately once every 17 months. Subsequent to cleaning this main, on January 3, 1931, a test made on September 5, 1931, showed a coefficient value of 133. On April 25, 1933, 20 months later, the coefficient had dropped to 106. On June 16, 1933, the main was again cleaned and a test on July 18, approximately one month after cleaning, gave a coefficient of 136. Six months later the coefficient had again dropped to 105.

The rapid loss of capacity after cleaning, as compared with the trend of capacity loss for new pipe, is illustrated in Figure 20, page 285. The quality of the supply carried is also shown on this diagram.

In summary it may be pointed out that prior to the last cleaning, the coefficient dropped from 136 to 105 in six months, whereas starting with a new pipe, seven years elapsed before a drop of equivalent magnitude was experienced. Average experience at Utica shows a capacity loss of 20 per cent. within six months after cleaning.

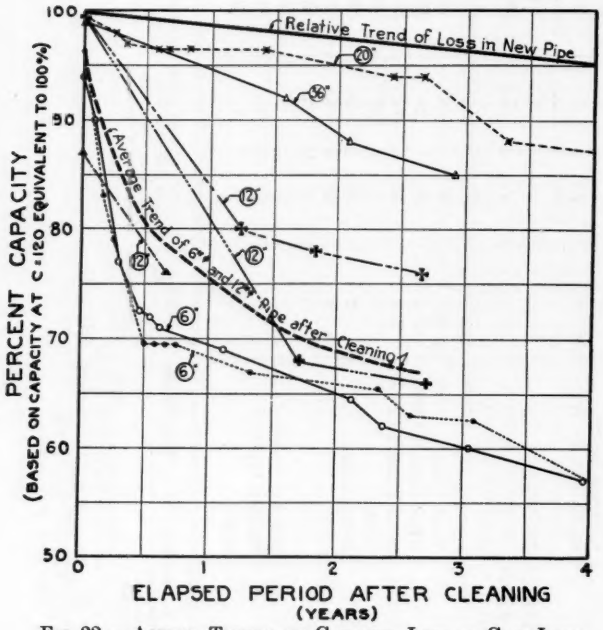

FIG. 22.— ACTUAL TRENDS OF CAPACITY LOSS IN CAST-IRON MAINS SUBSEQUENT TO CLEANING. ST. LOUIS, MO.

St. Louis, Mo. The trend of capacity loss subsequent to the cleaning of mains in St. Louis, Mo., is illustrated in Figure 22. These results are of particular interest because of the wide extent of the tests and the radical difference in water quality from that at Charleston, S. C., and Utica, N. Y.

Loss of capacity in the St. Louis mains is stated to be due to a combination of silting, tuberculation, and, in later years, incrustation by lime deposits. The quality

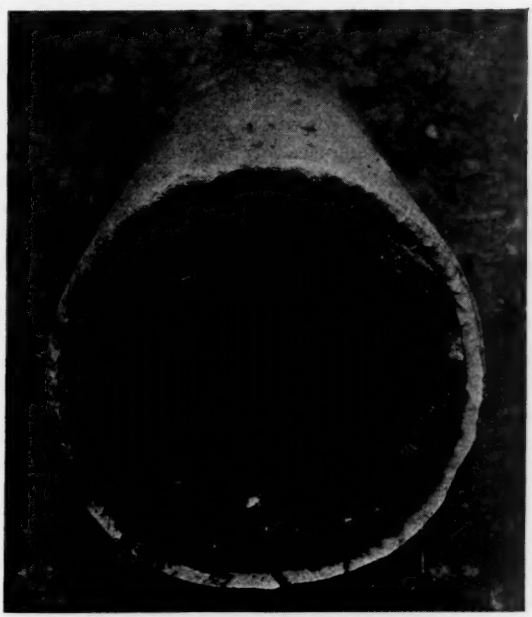

FIG. 23.— CHOKED CONDITION OF 16-IN. MAIN AT LAWRENCE, KANSAS, AFTER 47 YEARS OF SERVICE.

Diameter of water way reduced to 10.75 in. Cleaning increased the Williams-Hazen C to 115.

of water carried has varied widely in the past. Representative figures are: pH value 9.0; CO_2 11.3 p.p.m., and hardness 99.0 p.p.m.

Figure 22 shows that the capacity immediately after cleaning was 95 per cent. of the capacity when new, assuming that a value of C = 120 for four-year-old pipe was equivalent to 100 per cent. capacity. On small distribution mains, the percentage capacity-drop is 80 in six months; 75 in one year; 69 in 2 years; 61.5 in 3 years; and 57 in 4 years. Based on the average trend of new pipe at St. Louis, a pipe 4 years old would possess approximately 95 per cent. of its original capacity. This comparison is again indicative of the rapid loss subsequent to cleaning.

Figure 22 shows that the loss is much less pronounced for larger mains than for smaller ones.

In considering the question of capacity loss following cleaning, an analysis of the foregoing reports of actual experience does not necessarily give a true average picture of conditions subsequent to all cleaning operations. Where the loss following cleaning is relatively small, little attention has undoubtedly been paid to the trend of coefficient values. It is only in cases where early repetition of difficulties is manifest that subsequent tests are made and the results reported in the literature.

Quantity of Material Removed by Cleaning Operations. The quantity of material removed by cleaning varies widely, depending upon local conditions. There are three sources of available data as follows:

Merced, Cal. In cleaning 7 080 ft. of 16-in. pipe 36 years old, a pile of material in the form of a cone 4½ ft. in height and 10 ft. in diameter was removed.

St. Louis, Mo. The average amount of material removed by cleaning operations was:

Diameter (Inches).	Weight of Material Removed Lb. per Lin. Ft.
6	0.76 to 3.67
8	1.64 to 3.33
12	1.80 to 4.40
20	3.50 to 28.0
36	22.25 to 69.17

The material weighed 85 lb. per cu. ft., when wet, and 68 lb. per cu. ft., when dry.

Lawrence, Kan. A 16-in. main laid in 1886 developed in 47 years tubercles and deposits which reduced the waterway to only 34 per cent. of the original. The 16-in. main had a capacity before cleaning equal to that of a new 6-in. main. The condition of pipe is illustrated in Figure 23.

The value of C after cleaning was 115, estimated to represent 95 per cent. of the original capacity.

In cleaning 18.5 miles of mains from 5 to 16 in. in diameter, the material removed amounted to 35 per cent. of the cubical contents of the original mains.

REFERENCES.

1. Thos. J. Skinker. Cleaning Water Mains, Results and Costs. *Jour. Am. Water Works Assn.*, 21, June, 1929, p. 727. Cut of machine; extensive data on C before and after cleaning; drop in C subsequent to cleaning; costs; quantities removed.

2. Burt B. Hodgeman. Restoration of Old Distributing Systems. *Jour. Am. Water Works Assn.*, 1911, p. 40. Data before and after cleanings; good discussion.

3. C. M. Saville. Cleaning Water Mains at Hartford, Conn. *Eng. News*, 70, Nov. 11, 1913, p. 1098. Values of C before and after cleaning; plans of equipment; data; specifications; costs.

4. Cleaning a Water Supply Main at Merced, Cal. *Eng. News*, 74, July 22, 1915, p. 155. Flow before and after cleaning; cut of material removed.

5. Wm. Murdock. Report of Department of Public Works, Saint John, N. B. This JOURNAL, Sept., 1898, p. 147. Methods used; general effects.

6. Dexter Brackett. This JOURNAL, Sept., 1898, p. 343. Specific data on old Boston main.

7. Burt B. Hodgeman. Some Results of Pipe Cleaning. This JOURNAL, 39, 1925, p. 171. General experience; few specific data.

8. Cleaning Water Mains. This JOURNAL, 24, 1910, p. 373. No specific data.

9. C. M. Saville. Cleaning Water Mains at Hartford, Conn. This JOURNAL, 27, 1913. p. 489. Capacities before and after cleaning; costs; cut of equipment, specifications.

APPENDIX I.

COEFFICIENT VALUES OF STEEL PIPE.

Fred C. Scobey* has probably made the most complete study of carrying capacity of steel pipes. This bulletin is indispensable to all concerned with this question. Abundant information on the value of C for new steel pipe is presented by Scobey and can be supplemented from other sources. Data defining age-coefficient trends, however, are limited to a few pipe lines. In a number of cases two tests are recorded for the same pipe-line after a substantial intervening period of service.

In this report, discussion of coefficient values of steel pipe will be limited to a summary of the values for new steel pipe of different types, together with the presentation of such data on trend curves as have been furnished the Committee.

Classification of Steel Pipe. It is necessary to classify steel pipe according to type in considering coefficient values, because the many differences in fabrication and construction are reflected in the value of C. The classification suggested by Scobey is convenient:

Class 1 — Full Riveted Pipe. Pipe having both logitudinal and girth seams held by one or more lines of rivets with projecting heads. From a capacity standpoint pipe with countersunk rivet heads on the interior belongs in Class 3.

Class 2 — Girth Riveted Pipe. Pipe having no retarding rivet heads in the longitudinal seams, but having the same girth seams as full riveted pipe.

Class 3 — Continuous Interior Pipe. Pipe having the interior surface unmarred by plate offsets, or by projecting rivet heads in either longitudinal or girth seams. Not necessarily described as smooth.

Values of C for New Steel Pipe. Probable values of C for various classes of *new* steel pipe are listed in Table 11. The range in values for each class is presented in Tables 12 to 14.

* U. S. Dept. of Agriculture, Technical Bulletin 150, Jan., 1930, "The Flow of Water in Riveted Steel and Analogous Pipes."

TABLE 11.— SUMMARY OF VALUES OF THE WILLIAMS-HAZEN C FOR DIFFERENT CLASSES OF NEW STEEL PIPE.*

Class.	Description.	Value Suggested by Scobey. K's	Value Suggested by Scobey. C.	Average Value of C.
	Class 1.— Full Riveted Pipe.			
1-a	New sheet-metal pipe up to 3/16 in. thick	0.38	30 in. =120 6 in. =130	
1-b	New plate metal from 3/16 to 7/16 in. thick, with either taper or cylinder joints	0.44	120 in. =100 30 in. =110	
1-c	New plate metal from 1/2 in. up with either taper or cylinder joints, and for plate from 1/4 to 7/16 in. thick when butt-jointed		100	
1-d	New butt-strap pipe of plate from 1/2 in. up	0.48 0.52	24 ft. =90 10 ft. =95	
1.	Average			115.2(a)
	Class 2.— Girth Riveted Pipe.			
2.	Lockbar and hammer-weld pipe with lap- or flange-riveted field (girth) joints; electric-weld, hammer-weld, and drawn pipe with riveted bump joints	0.34	125	130.4(b)
	Class 3.— Continuous Interior Pipe.			
3.	All types sheet and plate metal pipe that offer a practically uniform interior surface of relative smoothness. Full welded, crimped slip joint, Lockbar with welded flange or leaded sleeve connections, bell and spigot, and bolted-coupling pipes all belong to this class	0.32	Above 30 in. =130 Small dia. =140	139.2(c)
	Miscellaneous Special Types of Pipe.			
...	Spiral riveted, flow with laps	0.44	110	131.4†(c)
...	Spiral riveted, flow against laps	0.48	100	....
...	Dredge pipe with clear water	0.38	...	118. (c)
...	Dredge pipe with dredged materials	0.44	...	....
...	Corrugated pipes	1.40	60	63.7 (c)

* Scobey's coefficient $K's$ is also listed in this table. This coefficient originates in the formula $V = \frac{H^{0.53} D^{0.53}}{K_S^{0.53}}$

Where V = Mean velocity in feet per second.
H = Friction loss per 1000 linear feet of pipe.
D = Mean inside diameter of pipe in feet.
K_S = Friction coefficient.
K'_S = Friction coefficient for *new* pipe.

† Laboratory results for test length of 60 to 80 ft.

(a) See Table 12. (b) See Table 13. (c) See Table 14.

TABLE 12.— SUMMARY OF 33 COEFFICIENT TESTS ON FULL RIVETED STEEL PIPE.

Age 1 Year or Less.

Technical Bulletin 150 U. S. Dept. of Agriculture.

Pipe No. in Bulletin 150.	Class.	Actual Age (Years).	Inside Diameter (Inches).	Length Tested (Feet).	Range of Velocities (Ft. per Sec.).	Average Value of Williams-Hazen C.
2	1a	N*	7.71	365.3	0.6–19.7	140.5
3	1a	N	8.0	264.5	1.2– 1.5	132.1
4	1a	N	8.0	4 354	7.2	117.6
5	1a	N	10.0	9 415	4.7	104.7
10	1a	N	11.22	365.5	1.3–10.5	135.1
16	1a	N	15.96	16 416.4	4.6	121.5
18	1a	1	16.99	4 438.7	20.1	126.8
30	1a	1	33.0	34 176	6.1	123.4
32	1a	1	35.0	39 829	5.4	127.4
35	1b	N	36.0	25 000	0.6– 5.7	110.0
45	1b	1	42.0	50 965	3.8	117.1
46	1b	N	42.0	5 574	1.8– 4.3	109.5
47	1b	N	42.0	....	1.4– 1.8	113.1
48	1b	N	42.0	81 139	2.1– 5.0	107.8
53	1b	N	47.28	26 687	2.6	105.6
53a	1b	1	47.28	26 687	2.6– 2.8	100.7
54	1b	N	47.34	61 445	5.4	106.7
55	1b	N	47.40	33 356	2.6– 3.4	115.2
55a	1b	N	47.40	74 396	3.6	111.8
56b	1b	1	47.4	20 415	2.0– 3.3	116.2
63	1b	N	62.0	1 123	1.9	120.0
64	1c	0.8	72.0	49 294	1.1– 3.3	110.7
65	1c	N	72.0	319.9	2.3–11.7	105.1
66	1c	N	72.0	583.4	2.3–11.7	114.1
67	1c	N	72.0	423.9	2.1– 3.0	111.5
68	1b	N	72.0	1 489.6	2.5– 3.0	130.6
69	1c	0.2	72.22	42 848	0.5– 3.8	105.6
72	1b	N	84.0	744.7	3.4– 8.3	106.1
73	1b	N	84.0	768	3.4– 8.3	112.9
74	1c	N	84.0	1 070.6	3.4– 8.3	108.7
75	1b	N	84.0	26 833	3.4– 8.3	109.1
78	1b	0.8	108.0	33 920	2.0– 7.0	113.8
79	1c	N	129.0	231	7.9–10.8	119.8
Average	....	....	51.55	....	....	115.2

* N = New.

TABLE 13.— SUMMARY OF 16 COEFFICIENT TESTS ON GIRTH RIVETED STEEL PIPE.

Age 1 Year or Less.

(Technical Bulletin 150, U. S. Dept. of Agriculture.)

Pipe No. in Bulletin 150.	Class.	Actual Age (Years).	Inside Diameter (Inches).	Length Tested (Feet).	Range of Velocities (Ft. per Sec.).	Average Value of Williams-Hasen C.
204	2	N*	4.12	....	1.3–23.4	137.5
206	2	N	5.12	....	1.9–20.6	134.9
208	2	N	6.14	....	1.0–16.9	138.3
210	2	N	8.05	....	1.5–13.0	135.6
211	2	N	8.94	15 240	2.0– 4.4	136.7
220	2	N	37.0	50 697.9	3.84	117.1
220a	2	1	37.0	50 697.9	3.76	114.5
226	2	N	58.0	8 702.4	6.24	140.6
226a	2	N	58.0	7 918.6	6.24	132.5
226b	2	N	58.0	30 964.4	6.24	136.2
226c	2	N	58.0	47 585.4	6.24	135.1
227a	2	N	65.0	118 380.3	3.86	128.8
227b	2–3	N	65.0	53 999.6	3.86	137.0
227c	2	N	65.0	117 021.8	3.86	135.3
228	2	N	96.0	240	14.2–19.5	113.9
230	2	N	108.0	515	11.0–15.5	113.1
Average	....	....	46.08	....	....	130.4

* N = New.

TABLE 14.— SUMMARY OF 19 COEFFICIENT TESTS ON MISCELLANEOUS SPECIAL TYPES OF STEEL PIPE.

Age 1 Year or Less.

(Technical Bulletin 150, U. S. Dept. of Agriculture.)

Pipe No. in Bulletin 150.	Class.	Actual Age (Years).	Inside Diameter (Inches).	Length Tested (Feet).	Range of Velocities (Ft. per Sec.).	Average Value of Williams-Hazen C.
			Continuous Interior Steel Pipe.			
302	3	1	3.63	1 000	2.6–11.7	147.0
304	3	1	65.72	1 000	1.1–10.0	142.1
310	3	1	8.0	1 000	0.3– 3.3	153.2
311	3	N*	14.0	27 888	8.3	139.8
313	3	1	26.0	18 400	2.9– 6.0	126.3
314	3	N	30.0	(a)	1.9– 2.1	127.0
Average	....	....	14.56	....	....	139.2
			Dredge Pipe.			
402	1a	N	15.0	2 075	6.9–13.7	114.4
404	1a	N	15.0	1 340	7.7–15.8	130.0
406	1a	N	15.0	780	8.3–19.0	110.6
Average	....	....	15.0	....	....	118.3
			Spiral Riveted Steel Pipe.			
502	1a	N	4.084	80.6	1.9–7.8	131.0
504	1a	1	4.084	60.01	1.5–7.0	129.4
506	1b	1	4.084	80.1	2.3–7.4	125.0
508	1a	N	5.962	60.01	1.6–6.6	133.2
510	1a	1	5.962	60.01	2.6–6.5	135.3
512	1a	N	5.943	60.16	2.0–6.7	131.9
514	1b	N	5.943	60.16	1.5–6.6	133.8
Average	....	....	....	....	....	131.4
			Corrugated Steel Pipe.			
600	....	N	8.88	200	1.1–1.7	65.3
602	....	N	24.0	1 037.85	1.6	65.5
602a	....	N	24.0	2 807.75	1.6	60.2
Average	....	....	....	....	....	63.7

* N = New. (a) 12 to 22 miles.

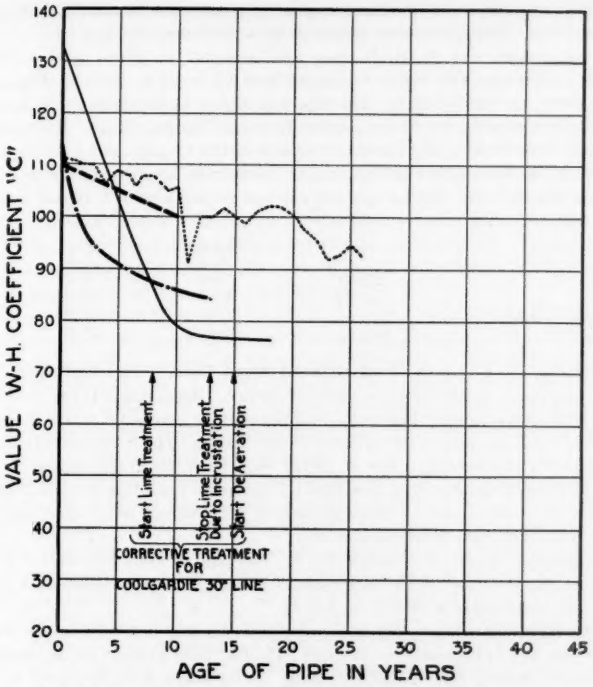
VALUE W-H. COEFFICIENT "C"
AGE OF PIPE IN YEARS
Start Lime Treatment
Stop Lime Treatment Due to Incrustation
Start DeAeration
CORRECTIVE TREATMENT FOR COOLGARDIE 30" LINE

FIG. 24.— ACTUAL TRENDS OF THE WILLIAMS-HAZEN C WITH AGE FOR STEEL PIPE LINES.

Solid Line: Coolgardie, Australia, 30-in. Lock-Bar steel pipe with bell-and-spigot joints.

Dotted Line: Rochester, N. Y., Conduit No. 2, 38-in. full riveted steel pipe.

Dash-dotted Line: Jersey City, N. J., 72-in. full riveted steel pipe.

Broken Line: Williams-Hazen predicted trend for steel pipe.

Actual Trend Curves for Steel Pipe. Three trend curves for steel pipe, showing the relation between age and the Williams-Hazen C are shown in Figure 24. Information relative to each of these curves is given below.

Jersey City, N. J., 72-in. Full-Riveted Steel Pipe. The actual trend of C in this line reached a value of C = 86 after 10 years of service. Since the value of C for the new pipe appears to have been 115, a capacity loss of 15 per cent. occurred during the first ten years of service. The Williams-Hazen Tables give no long-time trends for steel pipe. Two values are shown for pipe 72 in. and over in diameter: new riveted steel pipe C = 110, and steel pipe 10 years old C = 100. The theoretical loss in 10 years based upon these values would be 9 per cent.

This pipe was 72-in. full-riveted steel pipe with taper joints and plates from 5/16 to 11/16 in. in thickness. The appropriate classification after Scobey is Class 1-c.

The test section was 49 294 ft. long and included ten 48-in. gate valves with increasers and reducers. Test velocities ranged from 1.1 to 3.1 ft. per sec. The information is believed to be very accurate. The pipe was dipped horizontally in "Gilsonite."

The water carried by the line was taken from the Boonton Reservoir on the Rockaway River in New Jersey. For the first 10 years of the 13-year period covered by the trend curve, the water received no treatment. During the last 3 years (1908–1911) the water was disinfected with chlorine gas and calcium hypochlorite. A typical analysis of the supply follows:

		Average	Max.	Min.
pH value		6.9	7.2	6.7
CO_2	p.p.m.	3.0	3.2	2.9
Hardness	p.p.m.	33.0	34.0	32.0
Methyl orange alkalinity	p.p.m.	27.0	34.0	22.0
Total solids	p.p.m.	74.0	87.0	80.0

Rochester, N. Y., 38-in. Full-Riveted Steel Line. This line shows a trend reaching a value of C = 106 after ten years of service. Assuming a C for the new pipe of 115, the equivalent capacity loss would be 8 per cent. as compared with a loss of 9 per cent. assumed for 72-in. pipe in the William-Hazen Tables. The coefficient after 26 years of service was 93, representing a loss of 19 per cent. from the initial capacity. While a 1 000-ft. section of 36-in. cast-iron pipe directly upstream from this section of steel pipe was found to have developed a fibrous growth of polyzoa and fresh-water sponge, the 38-in. steel section showed tuberculation only.

The conduit is known as Conduit No. 2. The pipe is 38-in. full-riveted steel pipe with plates 1/4, 5/16, and 1/8 in. thick, with cylinder joints. It may be classified as Class 1-b. The actual inside diameter is said to be 3.17 ft.

In early tests rates of flow were computed from the drop in level of a large reservoir. The results were not particularly satisfactory. In later tests Venturi measurements were made. The test section was 45 393.9 ft. long. Head losses were measured with hook gages on water columns and piezometer taps at the upper and lower end of the test section. Professor Sabin's Japan coating was applied to the pipe. After dipping, the pipe was baked in an oven at high temperature for 10 hours.

Hemlock and Canadice Lakes are the source of supply. The water is chlorinated. Its quality is typified by the following analysis:

pH value		7.7
CO_2	p.p.m.	None
Hardness	p.p.m.	72.6
Methyl orange alkalinity	p.p.m.	51

Coolgardie, Australia, 30-in. Continuous-Interior Lock-bar Steel Line with Sleeve Joints. One of the most complete and interesting cases for which a trend curve for steel pipe may be developed is the Coolgardie line in Australia, which was placed in service in 1902. The history of this line provides information on the following important subjects:

(1) Rapid perforation by exterior soil corrosion, perforating in less than 3 years and producing 2 078 perforations in 12th year.
(2) Rapid tuberculation with a capacity loss of 42 per cent. after 10 years of service.
(3) Corrosion checked by corrective treatment with lime.
(4) Abandonment of lime treatment due to further capacity loss by incrustation.
(5) Adoption of de-aëration as a method of checking corrosion.

The estimated value of C, when the line was new, is 135. The average value for the entire 350 miles of pipe, after 10 years of service, was C = 78.7, representing a capacity loss of 42 per cent. Values of C in 12 sections tested separately varied from 57 to 96

after 10 years. Further loss of capacity was substantially prevented by corrective treatment of the water so that at the end of 18 years the average value of C for the entire line was 76.5.

The cost of the pipe line was £9 000 000. The reduction in capacity of 42 per cent. in 10 years represents a financial loss of $3 780 000, or $378 000 00 annually.

The Coolgardie line is 350 miles long, 30 in. in diameter and of Lock-bar construction with plates ¼ and 5/16 in. thick. The joints were formed by sleeves with bell ends and lead joints. Hence the original interior was entirely smooth, with no projecting rivets or plates.

The values of C shown in Figure 24 represent average values for the entire 350 miles. In conducting the tests, the line was divided into 12 sections. Values of C for each section were weighted according to the relative length of section in arriving at the composite averages shown for various years of service.

The intense summer heat (150 to 170 deg. F.) was recognized as a serious problem, and particular care was taken in an attempt to obtain a proper coating. Refined Trinidad bitumen was the chief component of the coating. The greater part of the line was dipped in coal tar mixed with equal parts of bitumen. On a quarter of the line, a California petroleum product called "Maltha," having the consistency of coal tar, was used in place of the coal tar, but in smaller proportion. The presence of mill scale was believed to have been a factor in aiding rapid corrosion.

The supply is taken from an impounding reservoir and is pumped through the line. The water is highly mineralized and contains magnesium sulphate, magnesium carbonate, calcium chloride, calcium sulphate, and calcium carbonate in quantities exceeding a grain per gallon. The water also contains a fair amount of organic matter, dissolved oxygen well up to the saturation point, and CO_2 to the extent of 2 p.p.m.

The line was laid late in 1902. In 1905 a serious loss of capacity was noted (C = 96.8), and in September, 1909, a committee reported upon the problem and recommended corrective treatment. Early estimates indicated that 3 grains per gallon of alkali would reduce the corrosive activity to $^1/_{13}$ of that of the untreated water and that the removal of all of the dissolved oxygen would reduce the corrosive activity to 1/16 of that of the untreated water.

Lime treatment was started in October 1910, when the line was 8 years old. The coefficient of the section beyond the point of application was then 94. Two years later the value had dropped to 74 due to incrustation. To prevent further capacity loss, lime treatment was discontinued in January, 1915, when the main was approximately 12 years old. De-aëration equipment was then designed and installed late in 1917.

REFERENCES:

See Proceedings Institution of Civil Engineers, Vol. 162, Paper 3516. See also F. F. Longley, The Coolgardie Pipe Line in Australia, and Measures Taken to Correct Corrosion, this JOURNAL, 39, Dec. 1925, p. 421.

APPENDIX II.

COEFFICIENT VALUES OF CONCRETE PIPE.

Practically no other type of pipe presents so wide a range of coefficient values as concrete pipe. Perhaps this may be attributed to the fact that relative head loss depends on two factors in particular: (1) surface texture or roughness which retards flow; and (2) relative uniformity of bore, or, in other words, undulation of the interior surface, which governs turbulence. It is, accordingly, obvious that variations in method of pipe manufacture and workmanship result in a wider range of coefficient values than is ordinarily observed for other types of pipe. Even when these factors are considered, however, the values reported cover a much wider range than would normally be anticipated. Coefficients as low as C = 85 and as high as 152 are reported. The former value was obtained for pipe manufactured many years ago with poor workmanship; the latter value was observed for modern methods of manufacturing pipe of large diameter with the aid of skilled workmen.

Coefficient values for cement-lined pipe have been discussed previously. Consideration of the coefficients of concrete pipe will be confined, therefore, to the following three topics:

(1) Coefficients of large-diameter concrete pipe manufactured by best modern methods and workmanship.
(2) Range of Coefficient values for various methods of manufacture.
(3) Effect of age on capacity.

Coefficients of Large-Diameter Concrete Pipe.

A typical record of the coefficients of large-diameter concrete pipe manufactured by best modern methods and workmanship, is provided by results obtained at Tulsa, Okla., and Denver, Colo., where long 54- and 60-in. precast, reinforced-concrete supply lines were installed. The following values of C were obtained shortly after the lines were put in service.

Location.	Date.	Diameter (Inches).	Length of Test Section (Feet).	Williams-Hazen C.	Relative Characteristics of Line.
Tulsa, Okla....	1925	60	80 898	152.4	Slightly sinuous.
Tulsa, Okla....	1925	60	34 788	145.4	29 bends aggregating 455.7 degrees.
Tulsa, Okla....	1925	54	21 047	152.1	Nearly Straight.
Denver, Col....	1925	54	38 274	146	
Average.....	....	....	....	149	

Description of Pipe. The pipe was made in 12-ft. lengths with 1:1¼:2 concrete, deposited in heavy rigid oiled vertical steel forms. The pipe was extremely accurate in dimension. Ten random sections, measured in two

diameters, showed an actual area conforming to the theoretical area within the third decimal place.

The "Lock Joint" type of joint was used, with steel joint rings and fibre-filled gaskets. The wedge-shaped joints on the pipe interior were subsequently filled with 1:1 mortar smoothed flush, to create practically a continuous smooth interior. The pipe was carefully spaded and later steam cured. A smooth dense surface, free from undulations, was obtained.

Test Methods. At Tulsa supervision, facilities and methods of tests, together with the long lengths of test lines, were conducive to unusual accuracy. Diameters of 10 pipe units were carefully measured, and accurate check levels were run between pressure stations. Water columns and mercury-tube manometers were used for measurement of head loss, and rate of flow was determined by a calibrated Venturi meter in the tests of the 60-in. line and by the color-velocity method for tests of the 54-in. line.

Similar test methods were adopted at Denver, except that all pressure gradients were determined by mercury manometers of the U-tube type, and rates of flow were obtained by double traverses of the pipe with a Pitot tube, checked by Venturi measurements.

Range of Coefficient Values.

The wide range of values reported for concrete pipe of various diameters and constructed by different methods is illustrated in Table 15. Results for pipes ranging in diameter from 8 to 216 in. and covering pipe constructed by both skilled and unskilled workmen, are included. Tests are tabulated in the order of descending values of C.

Table 15.— Coefficient Values for Concrete Pipe.*
(This Journal, Sept. 1924, p. 273).

Inside Diameter (Inches).	Length of Test Section (Feet).	Williams-Hazen C.	Description of Pipe Surface, Joints and Methods of Manufacture.
42	378	155.1	Tamped into steel forms, well wiped with oil prior to each pouring; interior surface unusually smooth; joints as smooth to the touch as the rest of the pipe.
216	6 466	152.8	Surface of pipe unusually smooth and even; great care taken to see that the concrete was carefully spaded next to the oiled steel forms.
46	9 774	151.5	Units cast in steel forms; pipe straight in alignment.
63.5	1 138	146.8	Steel used for interior forms; project manager inspected the pipe and found the interior in a very smooth, clean condition in eight years of operation.
31.5	131	146.5	Joints perfect.
30	....	144.0	Pipe units each 4 ft. in length, cast in wood forms that had been coated with No. 26 sheet steel.
110	....	142.7	
42	1 336	141.7	Tamped into steel forms, well wiped with oil prior to each pouring; interior surface unusually smooth; joints as smooth to the touch as the rest of the pipe.

* From Bulletin 852, Bureau of Public Roads, by Fred C. Scobey.

TABLE 15.— COEFFICIENT VALUES FOR CONCRETE PIPE — (Continued).

Inside Diameter. (Inches).	Length of Test Section (Feet).	Williams-Hazen C.	Description of Pipe Surface, Joints and Methods of Manufacture.
46	9 831	138.3	Units cast in steel forms; pipe straight in alignment.
174	8 419	136.8	Lining deposited against clean, oiled steel forms, being carefully spaded near the forms to assure a dense, smooth inner surface; surface somewhat foul.
36	7 282	136.0	Pipe units 6 ft. in length, cast on the ground in steel forms; joints caulked on inside with great care, the mixture being one part cement to two of sand.
86.6	4 200	135.6	Original data do not describe pipe manufacture or surface.
54	2 167	129.4	Description of pipe not given in Scobey's paper.
23.8	1 046	127.3	Pipe constructed with wood forms, both inside and out, longitudinal ridges made by the cracks in the boards, and a circular ridge at the end of each setting of the forms.
30	....	126.0	Comparing this 30-in. with 16-in. used on same work, notes say: "All sizes are grouted on the inside, but the grouting of the large size is more smooth."
20	2 163	125.0	Pipe units 3 ft. long; all units washed with cement grout before being laid. So far as could be determined, joints were well smoothed, and this pipe is probably typical of present-day careful practice (1911).
30.5	2 276	123.3	Joints not quite as nearly perfect as on the Victoria line; this probably accounts for some of the discrepancy in relative carrying capacities. Steel forms coated with oil gave a smooth surface to the interior of the pipe.
30	5 026	122.8	Pipe units were each 4 ft. in length, cast in wood forms that had been coated with No. 26 sheet steel; the values of K_s of about 0.330 are probably indicative of the silted condition within a smooth pipe rather than of the interior surface itself.
12	869	121.6	
20	....	121.4	
36	7 282	121.2	
36	1 933	118.6	
120	857	117.7	
19.7	772	115.8	
18	4 242	111.0	
16	1 897	109.7	
16	....	109.5	
18	559	106.6	
16	854	106.5	
12	218	103.3	
36	1 256	102.1	Wooden forms.
8	1 311	95.7	Clean, but with rough joints.

TABLE 15.— COEFFICIENT VALUES FOR CONCRETE PIPE — (Concluded).

Inside Diameter (Inches).	Length of Test Section (Feet).	Williams-Hazen C.	Description of Pipe Surface, Joints and Methods of Manufacture.
24	2 306	95.4	Gravel deposits in pipe.
16	785	95.3	Surface and joints not described.
19.7	1 116	94.2	2-ft. lengths; joints very rough.
29.9	880	93.1	3-ft. lengths; surface and joints not described.
10	1 107	93.0	No sediment; joints not described.
10	936	91.9	No sediment; joints not described.
12	218	90.7	2-ft. lengths.
18	133	90.2	Made by inexperienced men; sediment in pipe.
18	559	88.6	2-ft. lengths.
12	621	87.5	Poor joints, rough interior surface.
11.8	1 851	86.2	Rough joints, constructed by new man in business.

Classification of Values of C. The following classification of coefficient values of concrete pipe is taken from an admirable paper by Fred C. Scobey.*

Old "California" Pipe, Grade D, C = 90 ±. Pipe For Irrigation Practice. Dry mix, hand-tamped in moulds, immediately removed, 2-ft. lengths, rough texture, eccentric at joints resulting in shoulders.

New "California" Pipe, Grade C, C = 110–120. Relatively wet mix, machine-tamped into moulds, 2- and 3-ft. lengths, greater care in coating interior with cement wash and in wiping joints in assembled line.

Grade B Pipe, C = 120. Reasonably wet mix, well-oiled forms, adequate time of set before removal of forms, 2- to 4 ft.- lengths, neat cement wash.

Grade A Monolithic Pipe. (Approximately the same as for Class A Jointed Pipe.) Circular oiled metal forms — wet mix.

Poured Jointed Pipe. Grade A, C = 136.1 to 152.4, Averaging 145. Pipe for municipal Water-Works practice. Rich mixture, heavy rigid oiled vertical steel forms, 12-ft. lengths, diameters 30 in. or over, smooth joints, best workmanship.

Scobey's recommended values are summarized below.

Summary of Recommended Values of the Williams-Hazen C Applicable to Different Grades of Pipe for Municipal Water Supplies (After Scobey).

Grade A: Large new lines	140–150
Small lines — high velocities	130–150
Monolithic pipe may be placed in this class under best possible conditions, but usually should be placed in Grade B.	
Grade B: Jointed steel pipe, machine tamping, steel forms without oiling, 2- to 4-ft. lengths	120
Tunnel lining when placed with concrete gun behind oiled steel forms	120
Ordinary monolithic work	120
Grade C: Wet mix, 2- and 3-ft. lengths, moulds immediately stripped	110
Good wood-form monolithic work	110

Table 16 shows the available test data for lines which are representative of the various types of concrete pipe found in municipal water-works practice:

* *Jour. Am. Water Works Assn.*, Vol. 21, Jan. 1929, p. 1.

TABLE 16.—VALUES OF THE WILLIAMS-HAZEN C FOR VARIOUS TYPES OF CONCRETE PIPE.

Jour. Am. Water Works Assn., Vol. 21, Jan., 1929.

Reference Number.	Number Bulletin 852.*	Type and Location of Pipe.	Inside Diameter (Inches).	Age at Time of Tests (Years).	Length of Reach (Feet).	Range of Velocities (Feet per Second).	Year of Tests.	Length of Units (Feet).	Number of Tests.	Coefficients. Scobey K_s,	Coefficients. Williams-Hazen C	Coefficients. Kutter n.	Authority.	Remarks.
		Grade A. Jointed, poured pipe.												
1	29	Deer Flat Forest, Ida., U.S.B.R.	36.0	3–5	7,282	5.45–9.06	1915–7	6	6	0.404	136.1	0.0109	Scobey	Pipe straight; cast in steel forms; very wet mixture.
2	..	Birmingham, Ala.....	36.0	New	6,320	3.59–3.70	1928	12	2	0.397	141.5	0.0106	Berry .	Supply line beyond filter plant, pipe steam-cured in forms.
3	..	Norfolk, Va., supply line.....	36.0	3	11,458	2.89	1925	12	1	0.380	138.0	0.0112	Maury and Taylor	Lake Prince line; pipe steam-cured in forms.
4	..	Same pipe, another reach.....	36.0	3	13,043	2.90	1925	12	1	0.392	142.0	0.0109		
5	30	Victoria, B. C., inverted siphon on aqueduct.	42.0	1	1,336	1.01–2.91	1916	4	9	0.375	141.8	0.0112	Scobey	Classed as best grade 10 years ago; short units compared to present lengths.
6	31	Same line; a shorter siphon.	42.0	1	378	1.92–2.59	1916	4	4	0.393	146.8	0.0108	Scobey	Same as No. 5 and 6; on continuous curvature; steam cured.
7	33	R_1 Siphon, Umatilla project, U.S.B.R.	46.0	New	9,831	3.98–4.21	1912	8	4	0.390	138.3	0.0112	Newell	Straight in plan view; under 110-ft. head; coated with neat cement.
8	32	Same siphon, 4 years later.	46.0	5	9,774	1.41–3.17	1915	8	3	0.402	151.5	0.0105	Scobey	No. 7 tests required adjustment; No. 8 included friction loss only.
9	..	Conduit No. 10; Denver, Colo.	54.0	4	18,598	2.58–3.50	1925	12	2	0.409	151.0	0.0106	Scobey	Pipe quite straight; inside very smooth and slick from thin slime; see No. 3.
10	..	Same conduit; new portion.	54.0	New	19,676	2.58–3.50	1925	12	2	0.382	140.5	0.0112	Scobey	Simultaneous with No. 9 above; pipe sinuous vertically; see No. 3.
11	..	Two reaches above combined.	54.0	2 Av.	38,274	2.58–3.50	1925	12	2	0.395	146.0	0.0110	Scobey	From gage at upper end No. 9 to gage lower end No. 10 above; see No. 3.
12	..	Spavinaw Aqueduct, Tulsa, Okla.	54.0	New	21,047	2.63	1924	12	1	0.409	152.1	0.0106	Scobey	Units steam cured; line quite straight; near lower end of conduit.
13	..	Same aqueduct, another reach.	54.0	New	21,047	2.63	1924	12	1	0.402	152.4	0.0107	Scobey	Long reach; only 52 degrees of

12	..	Spavinaw Aqueduct, Tulsa, Okla.	54.0	New	21,047	2.63	1924	12	1	0.409	152.1	0.0106	Scobey	Units steam cured; line quite straight; near lower end of conduit.
13	..	Same.	60.0	New	80,898	2.25	1924	12	1	0.402	152.4	0.0107	Scobey	Long reach; only 52 degrees of bends in total; near upper third of conduit.
14	..	Same.	60.0	New	34,788	2.25	1924	12	1	0.386	145.4	0.0111	Scobey	At upper end of conduit; includes 456 degrees of bends; not curves.
		Grade A (continued). *Jointed, centrifugally cast pipe.* (*Tentative; need more data.*)												
30	..	Riverside, Cal., trunk line.	42.0	New	24,060	1.60–2.82	1927	8	5	0.403	150.0	0.0105	Scobey	Contains 700 degrees curvature; radii from 100 to 1,000 ft.
31	..	Same line, following No. 30 above.	42.0	New	6,226	1.60–2.82	1927	8	5	0.402	149.8	0.0106	Scobey	Straight in plan; 25 degrees in 4 gentle curves.
		Grade A (continued). *Monolithic; steel forms oiled.*												
40	35	Simms Creek siphon, U.S.B.R., Montana.	53.5	7	1,138	3.02–6.39	1915	..	6	0.407	147.0	0.0108	Scobey	On gentle sag curve; interior coated neat cement; very smooth.
41	37	Average of 8 siphons, Catskill Aqueduct.	110.0	..	Various	Various	1915	..	..	0.405	142.7	0.0109	Moore	Steel pipes lined with 2-in. grout placed on metal-covered wood form.
42	41	Ontario Power Conduit No. 2, Canada.	216.0	4	6,466	4.0–20.0	1913–4	..	..	0.427	152.8	0.0102	Johnston	Inside hand-polished with carborundum bricks; exceedingly smooth.
		Grade A (continued). *Thin linings in metal pipe. Placed tentatively in this grade.*												
50	..	Charleston, S. C., lined cast-iron pipe.	5.62	New	500	1.20–4.45	1922	..	6	0.407	137.3	.....	Gibson	Believe these first tests on cement-lined cast iron. See 51, 52, 53.
51	..	Same; very short reach.	5.87	New	250	2.46–5.61	1924	..	5	0.437	144.6	.....	Gibson	Discount somewhat; compare with No. 50, 52, 53.
52	..	Same; short reach for diameter.	15.5	New	500	0.89–2.01	1922	..	3	0.362	137.5	.....	Gibson	Believe longer reaches would have yielded more consistent results.

TABLE 16.—VALUES OF THE WILLIAMS-HAZEN C FOR VARIOUS TYPES OF CONCRETE PIPE (Concluded).

Reference Number.	Number Bulletin 852.	Type and Location of Pipe.	Inside Diameter (Inches).	Age at Time of Tests (Years).	Length of Reach (Feet).	Range of Velocities (Feet per Second).	Year of Tests.	Length of Units (Feet).	Number of Tests.	Coefficients. Scobey Ks.	Williams-Hazen C.	Kutter n.	Authority.	Remarks.
53	..	Same; short reach for diameter.	15.5	New	500	0.89–2.44	1923	..	7	0.353	128.6	.....	Gibson	Pipes 50–51 lined with 3/16-in. cement; No. 52–3 with 1/4-in.
54	..	England; mortar-lined steel.	30–36	New	57 010	3.34–4.40	1928	18	1	0.410	145.0	0.0105†	Gourley	Mortar-lined centrifugally; coating of "slick" manganese slime.
		Grade B. Jointed, poured pipe.												
60	18	Temescal Water Co., Cal.	19.9	4	2 163	0.99–2.54	1916	3	5	0.344	125.0	0.0117	Scobey	Reinforced; short lengths; inside coated with neat cement.
61	19	Wrought-iron, cement-lined pipe.	20.0	....	.....	0.95–4.04	1880	..	12	0.345	121.3	0.0117	Fanning	No description given by Fanning.
62	24	D_1 Siphon, Umatilla project, U.S.B.R.	30.0	New	5 280	3.39–3.61	1911	4	3	0.405	141.0	0.0106	Newell	Coefficients satisfy Grade A; description Grade B.
63	24a	Same pipe, 4 years later.	30.0	4	5 026	1.04–2.45	1915	4	3	0.331	122.8	0.0124	Scobey	Low velocities in siphon between canals subject to silting.
64	25	R_3 siphon, same project, Oregon.	30.0	4	3 658	2.73	1912	4	1	0.351	126.0	0.0119	Newell	Newell regards test highly; notes possibility of sand inside.
65	26	Prosser pressure pipe, U.S.B.R.	30.5	4	2 276	4.88–5.78	1916	4	7	0.362	123.3	0.0117	Scobey	Short lengths, in oiled forms until set; approaches Grade A.
		Grade B. Monolithic.												
70	39	Rondout Tunnel, Catskill Aqueduct.	174.0	New	8 419	1.58–4.67	1915	..	8	0.355	136.8	0.0124	Moore	Tunnel, lined with 17 in. of concrete spaded against oiled steel.
71	40	Wallkill Tunnel, Catskill Aqueduct.	174.0	New	13 941	1.58–4.67	1915	..	9	0.357	136.8	0.0124	Moore	Same remarks; also description and some of tests show almost Grade A.
		Grade C. Jointed, forms immediately removed.												

		Aqueduct.												and some of tests show almost Grade A.
		Grade C. Jointed, forms immediately removed.												
80	..	Santa Maria, Cal., supply line.	18	New	28 930	.....	....	3	1	0.337	119.7	0.0119	Neel	The best pipes of this construction approach Grade B. Applies to this pipe.
		Grades D to B. Monolithic wood forms.												
90	20	Clavey siphon, Oakdale, Dist. Cal.	23.7	3	1 046	1.55–1.95	1916	..	3	0.347	127.3	0.0117	Scobey	Rough construction and 1 test indicate Grade C; average, Grade B.

*U. S. Bureau of Public Roads, Bull. 852.

Effect of Age on Capacity of Concrete Pipe.

The capacity loss of concrete pipes is limited to the following causes:

(1) Incrustation.
(2) Slime or fungus growths.
(3) Silting.

Incrustation is extremely rare. Records are limited to a few cases where hard Middle-western waters have built up lime deposits on concrete drain tile. Slime or fungus growths have occurred in certain instances and are marked by quick development of the growth in new pipe and rapid return after cleaning. Silting, of course, is not affected by type of pipe material.

General experience indicates that the initial carrying capacity of concrete or cement-lined pipes will be relatively well maintained. In a few instances the formation on the pipe walls of a "slick," which is of negligible thickness, and very slippery has after a few years of service, produced capacities that may exceed the initial one. Three cases are shown in the following tabulation:

Location of Line Tested.	Williams-Hazen C Before and After Stated Time Interval.		Time Interval (Years).
	Before.	After.	
D_1 Siphon of the Umatilla project, Oregon, 30-in. reinforced-concrete pipe.....	144	123*	4
Deer Flat Forest pipe line, Boise project, Idaho, 36-in. reinforced concrete pipe	121	136	1
R_1 Siphon of the Umatilla project, Oregon, 46-in. reinforced-concrete pipe.....	138	151	3
Denver Conduit, No. 10, 54-in. reinforced-concrete pipe.....	141	151	3

* From Bulletin 852, Bureau of Public Roads, p. 36: "The values of C are probably indicative of the silted condition within a smooth pipe, rather than of the interior surface itself."

References.

(1) Manufacture of Pipe for Spavinaw Water Projects. *Eng. News-Rec.* 92, May 22, 1924, p. 899.

(2) Longley, F. F. Reinforced Concrete Pipe Lines for Water Supply Lines. This Journal, 38, Sept., 1924, p. 257.

(3) Scobey, Fred C. Flow of Water in Tulsa 60-in. and 54-in. Concrete Pipe Line. *Eng. News.-Rec.* 94, May 28, 1925, p. 894.

(4) Scobey, Fred C. Flow of Water in 54-in. Concrete Conduit, Denver, Colorado. *Eng. News-Rec.* 96, Apr. 29, 1926, p. 678.

APPENDIX III.

VARIOUS TESTS AFFORDING A DIRECT COMPARISON OF COEFFICIENT VALUES FOR DIFFERENT TYPES OF PIPE.

Some work has been done by what may be called tests of a "laboratory type" to determine relative values of C for different kinds of pipe. Such comparative tests have been carried out on lines especially constructed for testing, keeping the same personnel, running the lines in parallel, and in general providing unusual facilities for precise work. The coefficient values obtained in such tests are believed to be most reliable and to fix definitely the differences for the types of pipe interior tested. Information is available on the following direct comparative tests:

(1) Versailles, Pa., 1916. 8-in. cast-iron and 8-in. steel pipe, both tar-coated.

(2) University of Illinois. 4-, 6- and 8-in. tar-coated cast-iron and 4-, 6-, and 8- in. cement-lined cast-iron pipe.

(3) Versailles, Pa.. 1929. 12-in. cement-lined and 12-in. Talbot-lined steel pipe.

New Cast-Iron and Steel Pipe (Both Tar-Coated). These tests were conducted at Versailles, Pa., in July and August, 1916, by Alfred Steinbart, Harry R. Mazurie and Thomas Coleman, for the National Tube Company in order to determine:

(1) Relative frictional resistance of new wrought-steel pipe as compared with new cast-iron pipe of the same diameter.

(2) Difference in frictional resistance when direction of flow is into the bell ends and when flow is reversed.

The average values of C for velocities varying from 1 to 9 ft. per second, and based both on nominal and actual net diameters, which were identical for all practical purposes, were as follows:

8-in. tar-coated cast-iron pipe, Class B, 12-ft. lengths, bell and spigot joints, 8.014 in. actual inside diameter..... C=132

8-in. tar-coated 29 lb. per ft., lap-welded, wrought-steel pipe, 20-ft. lengths, Matheson bell joints, 8.026 in. actual inside diameter..... C=146

At the maximum velocity of 9 ft. per sec., the value of C was 128 for the cast-iron pipe and 145 for the steel pipe.

The following conclusions were drawn:

(1) The capacity of this type of tar-coated steel pipe when new is 10 per cent. greater than that of new tar-coated cast-iron pipe of the same diameter.

(2) While reversal of direction of flow in relation to bell ends results in a measurable difference of head loss, the difference is so small that it can be neglected.

(3) Tests at various velocities indicate that an increase in relative head loss with consequent drop in value of C develops in cast-iron pipe at velocities of about 6 ft. per second. This was not so apparent in the steel pipe until slightly higher velocities were reached.

The two lines were 1 000 ft. long between measuring stations, laid on absolutely straight line and grade, and parallel to each other, 2 ft. 4 in. apart center to center. The lines were arranged in series, connected at one end of the test stretch with a 90-degree

bend, and straight sections 105 ft. long were provided ahead of all measuring points to assure proper flow conditions.

A total of 336 measurements of diameter at pipe ends was made by a micrometer caliper. As a check, four lengths of each type of pipe were filled with water, lengths were measured, the water weighed, and diameters computed. The diameters were 8.014 and 8.026 in. for the cast-iron and steel pipe respectively.

The flow was circulated through a 420-cu. ft. tank by a horizontal centrifugal pump running 1 650 to 1 700 r.p.m., belt driven from a 75-hp., 500-r.p.m. constant-speed motor. Rate of flow was obtained by Venturi meter and checked by a Cole Pitometer. Differences ranged from 4 per cent. at 2 ft. per sec. to ½ per cent. at 9 ft. per sec.

Measurements of head loss were made with U-tube mercury manometers. Pressures were taken from the main by a pressure ring with eight ¼-in. holes on the pipe circumference, and transmitted to the U-tubes through ½-in. pipe.

New Tar-coated Cast-Iron and Cement-lined Cast-Iron Pipe. These tests were conducted under the direction of Melvin L. Enger at the Hydraulic Laboratory of the University of Illinois, for the American Cast Iron Pipe Co., of Birmingham, Ala. A complete report of these tests has appeared in the *Journal of the American Water Works Association.** The purpose of these tests was to determine the relative loss of head in tar-coated as against cement-lined cast-iron pipe at various rates of flow.

The results of these tests are shown in the following tabulation:

Type of Pipe.	Nominal Diameter (Inches).	Actual Net Diameter (Inches).	Williams-Hazen C.†	
			Based on Nominal Diameter.	Based on Actual Net Diameter.
Tar Coated.....	4	3.96	132	135
	6	5.88	135	143
	8	7.97	132	134
Cement Lined.....	4	3.61	113	149
	6	5.84	141	150
	8	7.86	144	152

The conclusions reached are:

(1) The average coefficient value of small cast-iron pipe with centrifugally applied cement lining is C = 150, based on actual net diameter and ideal alignment conditions.

(2) The capacity of *new* 4-in. tar-coated cast-iron pipe is 17 per cent. greater than for 4-in. cement-lined pipe due to encroachment of the cement lining on the diameter.

(3) Cement-lined pipe, 6 and 8 in. in diameter, is sufficiently smoother than tar-coated pipe to offset diameter encroachment by lining, so that the excess capacity of cement-lined pipe over unlined pipe will be 5 per cent. for 6-in. and 9 per cent. for 8-in. pipe.

(4) At velocities of 1 to 2 ft. per sec., cement-lined pipe having an internal diameter 3 per cent. less than new tar-coated pipe will have about the same capacity.

(5) At velocities of 9 to 10 ft. per sec., cement-lined pipe having an internal diameter 7 per cent. less than new tar-coated pipe has about the same capacity.

The length of the test lines varied from 181 to 218 ft. The pipes were laid parallel to each other and were connected in series. They were very carefully laid to straight line and grade, with joints of lead and jute.

* Vol. 18, October, 1927, p. 409. † Average throughout velocity range.

Diameters were determined by measuring the inside vertical and horizontal diameters about 8 in. from the end of each pipe used. The rate of flow was measured by an 8-in. by 3½-in. Venturi meter, calibrated in place by discharging into a pit. For low rates, carbon tetrachloride was used in the differential gage; at high rates, mercury was employed. Water was pumped through a standpipe 4 ft. in diameter and 60 ft. high to absorb pump pulsations.

Head losses were measured by differential gages connected through a ½-in. pipe to pressure rings at each end of the test section. Mercury gages 5-ft. high were used for high rates and carbon tetrachloride gages 15-ft. high for low rates.

Steel Pipe with Cement and Talbot Lining. These tests were conducted at Versailles, Pa., in July, 1929, by the National Tube Co. The conditions of testing, length of line and methods adopted were the same

CEMENT-LINED STEEL PIPE.

Lining applied centrifugally; outside diameter 12.75 in.; inside diameter 12.09 in. before lining; actual net diameter 11.426 in.; lining thickness 0.332 in.; Matheson bell and spigot joints.

Velocity Ft. per Sec.	Loss of Head Ft. per 1 000.	Williams-Hazen C. Based on Inside Diameter Before Lining.	Williams-Hazen C. Based on Actual Net Diameter.
2.56	1.70	129	150
3.58	3.21	129	148
5.01	6.06	127	148
5.63	7.57	128	148
6.87	10.88	127	147
8.20	15.38	126	146
9.24	19.35	126	146
Average		127	147

TALBOT-LINED STEEL PIPE.

Lining applied centrifugally; outside diameter 12.75 in.; inside diameter 12.09 in. before lining; actual net diameter 11.324 in.; lining thickness 0.383 in.; Matheson bell and spigot joints.

Velocity Ft. per Sec.	Loss of Head Ft. per 1 000.	Williams-Hazen C. Based on Inside Diameter Before Lining.	Williams-Hazen C. Based on Actual Net Diameter.
2.60	1.63	131	156
3.63	3.01	131	157
5.08	5.65	132	156
5.74	6.87	134	159
7.01	9.95	134	159
8.36	13.90	133	158
9.42	17.40	132	159
Average		133	157

as described in connection with the tests on 8-in. cast-iron and steel pipe, run by the same company in 1916. The results, may be considered unusually precise. It was the purpose of these tests to determine the

relative head loss in steel pipe with cement lining as against Talbot lining, both linings being applied by the centrifugal method. Matheson joints were employed and the pipe was 12 in. in diameter.

The coefficient values determined by these tests on lines 1 000 ft. long are summarized in the tabulation on page 333.

It appears, therefore, that the value of C for 12-in steel pipe is 147 if the pipe is lined centrifugally with cement, and 157 if a Talbot lining is applied; both results are based on actual net diameter. A summary of these tests has also been published by H. R. Redington, T. L. W. Birkinbine and F. N. Speller*.

*Jour. Am. Water Works Assn., 23, Nov., 1931, p. 1649.

APPENDIX IV.

EFFECT OF VELOCITY ON VALUES OF WILLIAMS-HAZEN COEFFICIENT.

There exists a theoretical basis for the fact that the value of the Williams-Hazen C is slightly affected by the magnitude of velocity obtaining during the test. Such effects are negligible, however, in comparison with other more important factors of precision of measurement in most ordinary tests. It is accordingly believed that while this question may be considered properly in connection with tests permitting a "laboratory degree of accuracy," an average value for the Williams-Hazen C describes adequately all ordinary field tests of pipe capacities and capacity trends.

Conclusions. If any conclusions may be drawn from the data studied, as to the effect of velocity on coefficient values, they would be as follows:

(1) Within the limits of ordinary precision, the coefficient values may be greater or less than the average precision either at low or at high velocities.

(2) The apparent trend is toward a decrease in the value of C as velocities increase.

(3) This trend is more pronounced for unlined steel or cast-iron pipe than for pipe with a smooth lining.

(4) It is possible that a greater degree of turbulence, due to a slightly rough interior, may not occur until relatively high velocities are reached in lined pipe.

(5) If this is true, excessive drafts may be accompanied by very low coefficients in badly tuberculated pipe.

Field Tests on Full-Riveted Pipe. The results of ten series of tests on full-riveted pipe, each series including a wide range of velocities, indicates the degree to which C may be affected. Selecting the test at lowest velocity in each series, it was found that for an average velocity of 1.65 ft. per sec. the average coefficient was 120. Selecting the test at highest velocity in each series, the average velocity was 7.77 ft. per sec. and the average coefficient 115.

Field Tests on Girth-Riveted Pipe. For a group of 5 series of tests on girth-riveted pipe, the average results of the tests at lowest and highest velocity were as follows:

	Test at Lowest Velocity in each Series.	Tests at Highest Velocity in each Series.
Average Velocity — ft. per sec.	1.35	19.36
Williams-Hazen C	129.6	120

Tests on Tar-Coated Cast-Iron Pipe. (With facilities for a laboratory degree of accuracy). The following results show relatively small variations in the value of C throughout a wide range in velocity. These tests were conducted under conditions which favored greater precision than is possible in ordinary field tests.

Size of Pipe Inches.	Loss of Head Feet per 100.	Velocity Ft. per Sec.	Williams-Hazen C Based on Nominal Diameter.
8	0.18	0.578	142
	0.90	1.28	132
	1.90	1.92	132
	5.0	3.20	131
	7.2	3.84	129
	9.5	4.49	130
	19.0	6.40	127
	40.0	9.60	128
Average *	....	....	130
6	0.40	0.74	141
	0.59	0.91	141
	0.90	1.14	141
	4.0	2.52	139
	8.0	3.60	136
	20.0	5.70	132
	30.0	7.08	132
	40.0	8.17	130
	50.0	9.12	128
	60.0	10.30	132
	75.0	11.40	130
Average	....	....	135

Another series of tests on tar-coated cast-iron pipe, conducted under different auspices, but with similar methods of control favoring unusual precision, gave the following results on an 8-in. pipe:

Loss of Head Feet per 1 000.	Velocity Ft. per Sec.	Williams-Hazen C Based on Nominal Diameter.
0.75	1	114
2.00	2	134
4.00	3	138
7.2	4	135
11.25	5	133
15.50	6	133
21.8	7	130
28.2	8	129
35.3	9	128
Average †	....	132

* Excluding first value which is unreliable due to fact total measured head was only 0.035 ft.
† Excluding first value which involved so small a total loss as to prevent reliable measurement.

Tests on Cement-lined and Talbot-lined Pipe. Tests on lined pipe with a velocity range of from 2.5 to 9.5 ft. per sec. conducted with every possible precaution to obtain accurate measurements show surprisingly uniform values of C as indicated in the following tabulation:

Type of Pipe.	Loss of Head Feet per 1 000.	Velocity Ft. per Sec.	Williams-Hazen C Based on Actual Net Diameter.
12-in. cement-lined steel pipe.....	1.70	2.56	150 14
(Actual net diameter 11.437 in.)	3.21	3.58	145.63
	6.06	5.01	147.98
	7.57	5.63	147.40
	10.88	6.87	147.87
	15.38	8.20	146.41
	19.35	9.24	145.74
Average.....	....	....	147.74
12-in. Talbot-lined steel pipe.....	1.63	2.6	156.88
(Actual net diameter 11.313 in.)	3.01	3.63	158.14
	5.65	5.08	156.65
	6.87	5.74	159.26
	9.95	7.01	159.24
	13.90	8.36	158.54
	17.40	9.42	158.24
Average.....	....	....	158.14

APPENDIX V.

LIST OF CONTRIBUTORS.

The Committee gratefully acknowledges the coöperation of the following contributors who have provided the information that has made possible the compilation of this report:

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APPENDIX VI.

QUESTIONNAIRE FORMS CIRCULATED BY THE COMMITTEE.

In order that the reader may see the scope of the data upon which this report has been based, the questionnaire forms circulated by the Committee are reproduced below. These forms may be of service in outlining essential considerations for those who may wish to determine trend curves for their particular system.

Where special conditions were encountered, the regular forms were supplemented by correspondence.

NEW ENGLAND WATER WORKS ASSOCIATION.
COMMITTEE ON PIPE LINE FRICTION COEFFICIENTS.
Data Relative to Tests to
Determine Friction Coefficients.

(a) *Data submitted by*
Name.....
Address.....

(b) *Location of Test*
City.....
County.....State.....

(c) *Date of Test*
.....

(d) *Description of Pipe Material in Line Tested*
(Please state data on specifications, class, thickness, type of joints, etc.)
.....
.....
.....

(e) *Description of Interior Coating or Lining Material and Method of Application*
(Please state material specification and method of application such as dipped, brushed hot or cold application, centrifugally applied, etc.)
.....
.....
.....
.....
.....

(f) *Pipe Diameter*
(Please state method and extent of actual diameter measurements.)
Nominal Diameter.....inches
Specified Lining Thickness..... "
Computed Net Diameter..... "
Measured Average Diameter..... "
Averaged Based on Measurement of..... specimens

(g) *Age of Pipe at Time of Test*
.....Years. Per cent of Time in Service.....

(h) *General Factors Affecting Friction Coefficient*
(Please state length of individual pipe, whether 12 ft., 16 ft. etc.; also comments as to prevalence of bends, tees, corporation cocks and other sources of interference to flow.)

.....
.....
.....
.....
.....

No. of Valves..... Tees.....
90° Bends..... 45° Bends.....
Average Spacing of Corp. Cocks.....

(i) *History of Cleaning of Pipe Line*
(Please state whether pipe line had been cleaned and if so, the date thereof.)

.....
.....
.....

(j) *Quality of Water*
(Please send any complete available data relative to quality, also comments as to possible accumulation of sand or mud in test line.)

	Average	Max.	Min.
pH	.....	.....	.....
CO_2 p.p.m.	.....	.....	.....
Hardness p.p.m.	.....	.....	.....
Suspended Residue p.p.m.	.....	.....	.....

Surface Supply ☐
Ground Water ☐
Untreated ☐

Brief Description of Treatment.....

(k) *Methods of Conducting Tests*
Length of Section Tested..... Feet
Method of establishing static difference in elevation between upstream and downstream station:
By Leveling ☐
By Pressure Gage Readings ☐
Method of Measuring Volume of Flow:
By Disc Meters ☐
By Venturi Meters ☐
By Displacement of volume in storage tanks ☐
By Weirs ☐
By Pitometer ☐
By Hydrant Pitots ☐
By.....
Method of Measuring Friction Head:
By Pressure Gages ☐
Maximum Possible Reading on Gages Used..... No. sq. in.
Were Gages Calibrated Before Test.....
After Test.....
By Differential Manometer ☐
With Mercury ☐
With Carbon Tetrachloride ☐
Water Column ☐
By.....

(l) *Hydraulic Conditions During Tests*

	Average	Max.	Min.
Rate of Flow g.p.m.....	.....	.....	.....
Velocity through Actual Net Pipe Area. Ft. per Second.....	.....	.....	.....
Static Head:			
At Upstream Station..	.....	.....	.....
At Downstream Station	.....	.....	.....
Total Loss of Head Developed between Upstream and Downstream Stations. Feet of Water.	.....	.....	.....

(m) *Comments by Test Supervisor* as to his estimate of accuracy of results and details of test methods used

.....

.....

.....

.....

(n) *Results*

Value of Williams-Hazen "C" Based on Nominal Diameter.....

Based on Actual Net diameter.....

(o) *Remarks*.....

.....

.....

.....

.....

In addition to the blanks provided for data on this questionnaire, the following information will be of extreme value to the Committee:

(a) Photographs of sections or pieces of the pipe tested.

(b) Results of test where the basic data have been determined, even although computations have not been carried to the final conclusion and a value for "C" obtained.

(c) Complete information as to analyses indicating quality of water.

(d) Any data indicating whether or not character of water changed in passing through test section.

(e) Data relative to a change in source and consequently in quality of supply passing through lines tested.

SUPPLEMENTARY QUESTIONNAIRE RELATIVE TO QUALITY OF WATER.

Quality of Water

	Average	Max.	Min.
pH	.....	.....	.....
CC_2 p.p.m.....	.....	.....	.....
Hardness p.p.m.	.....	.....	.....
Suspended Residue p.p.m.	.....	.....	.....
Total Organic Residue p.p.m.	.....	.....	.....
Alkalinity M. O.....	.....	.....	.....

Type of Supply
(Please check one.)

Surface Supply ☐ No Treatment ☐

Ground Water ☐ Chlorination only ☐

Brief Description of Treatment

.....

.....

.....

.....

Date Treatment Adopted

.....

.....

Sources of Supply From.....To.....

.....

.....

From.....To.....

.....

.....

.....

.....

.....

RECENT CHANGES IN ADDRESS.

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Now: 50 Potter St., Cranston, R. I.

CARMODY, THOMAS J., Water Commissioner, Holyoke, Mass.
Formerly: 496 High St., Holyoke, Mass.
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